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The Tidal Cycle of 18·6 Years in the Oceans

By

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THE semi-diurnal and diurnal variations of sea-level in the oceans have been studied very carefully and the results of the researches have been published in a considerable number of papers. The drawing of tidal charts has in these cases been facilitated by the availability of extensive data covering practically all the coasts of the oceans. PROUDMAN has pointed out, however, that there is still "the absence of complete justification of the results presented for the great oceans" (7). As regards the monthly averages used for the determination of the mean annual oscillations in sea-level the material is considerably more restricted, but still comprehensive enough to allow regular characteristics of some regions to be clearly perceived (4, 6). It is evident that when we move on to the 18·6-year tidal cycle, the difficulties are still greater. It is true that the number of stations at which sea-level observations have been made over a period of at least 18–19 years is considerable, but it would certainly be a very questionable undertaking to determine the amplitude and the phase lag of this component on the basis of a single period. The effect of occasional disturbances caused by different meteorological factors or by errors in the original observations may in such cases become of decisive importance and distort the results. We have therefore tried, as far as possible, to limit our research on the 18·6-year cycle to stations at which sea-level has been recorded, and data are available, for a period of at least 37 years. Only in relatively few cases have we used stations with a shorter period of uninterrupted observations. It is therefore by no means surprising that Table 1 contains only a limited number of stations situated on the oceanic coasts and, moreover, that their regional distribution is very uneven. The southern hemisphere in particular is poorly represented. In view of these facts, accurate determination of the phenomenon as a whole is almost impossible, and we realize that to demonstrate the outlines of the 18·6-year oscillation of sea-level in the oceans is a difficult and uncertain undertaking. Our conceptions will no doubt be changed

considerably as soon as sufficiently long series of observations are available for several stations.

The stations on which this research is based are listed in Table 1. The greater part of the observational data used has been published by the "Association d'Océanographie Physique" (1); the values for Oslo are taken from a paper by TROVAAG and JESTRUP (8), and the data for Esbjerg have been published, up to and including the year 1950, by DIETRICH (3). Table 1 shows that in seven cases i. e., Takoradi, Portland, and Ketchikan, and the four stations on the western Pacific coasts, are the figures for the 18·6-year constituent based on only one complete period of observations.

The original data have not been corrected for the effects of different meteorological and hydrographical factors. In order to avoid the disturbing influence of exceptional years, however, it seemed necessary to smooth the yearly averages, at least to some degree, and the trinomial formula $\frac{a+2b+c}{4}$ was used for this purpose. The next step was to eliminate secular variations in sea-level, in order to avoid a systematic error in the computed harmonic constants. EGEDAL, DISNEY, and ROSSITER have each reported on the interesting problem of land upheaval and have given values for the secular variation in sea-level at a great number of stations all over the world in papers published by the "Association d'Océanographie Physique" (2). These values have been determined by the method of least squares. These extensive studies show that the secular variation of sea-level is a very complex phenomenon and that comparable estimates of these variations may be derived only from observations covering approximately the same number of years. As we had at our disposal sea-level data only up to the year 1946, while the authors mentioned above used, at least in some cases, observations which included 1951 or covered periods deviating from ours in other ways, the best solution seemed to be to determine the secular variation for the available series by the method of least squares. The results, recorded in Table 1, differ on the whole very little from the figures given by EGEDAL, DISNEY, and ROSSITER. In a few cases, however, — for instance, Sydney — the difference is considerable, but this fact is by no means surprising, as the results are based on very different periods.

The long-period rise or fall of sea-level having been eliminated from the observations, the 18·6-year tidal constituent was computed by harmonic analysis; the results are given in the last two columns of Table 1. The phase lags are determined with regard to the year 1932, which is characterized by maximum lunar declination and may therefore be considered appropriate as the initial year. Thus, in Table 1, a phase lag of about 180° indicates a year with minimal lunar declination.

While investigating long-period tidal phenomena in the sea and the terrestrial atmosphere, MAXIMOV (5) examined the 19-year constituent by means of periodograms. His results differ in some respects from those given in this paper, because he did not consider the lunar period as strictly fixed, but as varying for the separate stations between 17·8 and 21·2 years. In spite of this, MAXIMOV was able to show that there is a difference of

Table 1

Station	Sea	Latitude	Longitude	Period	Complete series of 18·6 years	Secular variations cm./100 years	18·6 year constituent	
							Amplitude, cm.	Phase lag
Rönnskär	Baltic	63°04′N.	20°48′E.	1867–1910	2	–76	0·7	63°
Utö	—	59°47′	21°22′	1867–1954	4	–29	0·6	98°
Oslo	North Sea	59°54′	10°45′	1914–1950	2	–37	3·8	268°
Esbjerg	—	55°28′	8°27′	1890–1950	3	12	1·5	291°
Hoek van Holland	—	51°59′	4°07′	1864–1946	4	24	0·4	291°
Cherbourg	Engl. Channel	49°39′	1°37′W.	1891–1944	2	–6	2·6	9°
Brest	Atlantic	48°23′	4°29′	1861–1943	4	11	1·6	29°
Biarritz	—	43°29′	1°34′	1889–1938	2	–3	3·5	22°
Lagos	—	37°06′	8°40′	1909–1946	2	20	1·7	48°
Cadiz	—	36°30′	6°12′	1880–1919	2	5	3·4	87°
Marseille	Mediterranean	43°18′	5°21′	1885–1946	3	13	0·9	82°
Takoradi	Atlantic	4°53′	1°45′	1929–1946	1	60	0·4	135°
Buenos Aires	—	34°36′S.	58°22′	1905–1946	2	12	1·5	236°
Galveston	Gulf of Mexico	29°19′N.	94°47′	1909–1946	2	56	1·4	237°
Baltimore	Atlantic	39°16′	76°35′	1903–1946	2	29	1·6	93°
Portland	—	43°40′	70°15′	1912–1945	1	10	3·1	88°
Ketchikan	Pacific	55°20′	131°38′	1919–1946	1	1	1·1	49°
San Francisco	—	37°48′	122°28′	1898–1946	2	17	0·7	126°
Honolulu	—	21°18′	157°52′	1905–1946	2	23	1·9	138°
Hanasaki	—	43°17′	145°35′E.	1900–1924	1	37	1·9	154°
Aikawa	—	38°18′	141°30′	1900–1924	1	8	1·4	154°
Takao	—	22°37′	120°16′	1904–1933	1	22	1·0	177°
Sydney	—	33°51′S.	151°14′	1897–1927	1	11	2·4	341°
Rangoon	Indian Ocean	18°46′N.	96°10′	1880–1920	2	3	0·6	128°
Port Blair	—	11°41′	92°46′	1880–1920	2	20	1·2	67°
Bombay	—	18°55′	72°50′	1878–1946	3	1	0·7	60°
Karachi	—	24°48′	66°58′	1868–1920	2	8	0·6	55°

approximately 140° between the mean phase lags of the Atlantic and the Pacific.

ROSSITER (2) attempted to compute the harmonic constants of the 18·6-year cycle for the North Sea. The amplitudes and phase lags of the constituents were determined for three ports in this area, Dunbar, Newlyn, and Den Helder, on the basis of two separate, but partly overlapping, periods. ROSSITER's computations show a satisfactory conformity and agree, on the whole, with those given in this paper for the sea area in question. ROSSITER also studied the 18·6-year constituents for Aberdeen, but for this station, at which the average sea-level alternately rises and falls during different decades, the phase lags do not show such close agreement.

The 18·6-year constituents determined by harmonic analysis, which are given in Table 1, refer to 27 stations. In the choice of stations, particular stress was laid on the oceans, and the smaller sea basins were considered chiefly for the sake of comparison. The fact is that the 18·6-year oscillation may be expected to obey special rules in enclosed basins, so that the phenomenon there may differ considerably from that prevailing in the oceans and in correspondence with semi-diurnal and diurnal constituents, it may be characterized by very small amplitude.

The first two entries in the table refer to two Baltic stations, Rönnskär and Utö. We may note firstly, that amplitudes in the Baltic are, on an average, less than those in the North Sea, and secondly, that there is a difference of about 160° between the phase lags in these sea areas, which indicates that this component is of approximately opposite phase. In the North Sea the amplitudes vary from 0·4 to 3·8 cm., though the latter value, for Oslo, is probably due to local influences. Comparing the North Sea with the English Channel, we find that the most pronounced difference is the retardation of phase lag by about 80°, corresponding to nearly 5 years. A slight retardation may, moreover, be noted between Cherbourg and the European coast of the Atlantic, but the agreement between the phase lags at the three stations on the Atlantic coasts, Brest, Biarritz, and Lagos, is quite surprisingly good, especially in view of the very different periods covered by the data used for the computation of the harmonic constants. The maximum deviation amounts to only 26°. Cadiz might be expected to belong to this group, but its phase lag shows much better correspondence with Marseilles, in the Mediterranean. Proceeding southwards, we have only one station on the African coast, viz., Takoradi, at which sea-level observations have been made over a period long enough to be useful for our purpose. The values obtained for this station based on only a single period, must be treated with great caution, but they seem to indicate a further phase-lag retardation. It is to be hoped that longer periods of observations taken at more numerous stations will enable more positive conclusions to be drawn in the future.

The American coast of the Atlantic is represented in Table 1 by four stations, though one of them, Galveston, lies in the Gulf of Mexico. The two stations, Baltimore and Portland on the Atlantic coast of the United States show very good agreement in their phase lags, whereas a difference of about 150° exists between the phase lag for the pair of stations, and that for Galveston and Buenos Aires. This indicates that the occurrence of a maximum at the former pair of stations corresponds fairly closely with a minimum at the latter pair, and vice versa. In this respect the differences between the west coast of the North Atlantic and the Gulf of Mexico are in general similar to those between the North Sea and the Baltic. There also seems to be a retardation of the phase lag from north to south along the west coast of America.

Before leaving these groups of stations, we may point out that comparison of European with North American stations in roughly the same latitudes shows a phase-lag difference of about 58°, while the average difference in longitude is 68°. This suggests that the retardation of the 18·6-year component from east to west in the Atlantic is of the same magnitude as the difference in longitude.

If the number of stations on the coast of the Atlantic is less than satisfactory, the position in the Pacific is still worse. Our table contains only seven stations for this ocean, five of which have data for only one complete period. However, the harmonic constants for the three stations on the Asiatic coast of the Pacific agree fairly well, and show even smaller differences in phase-lag retardation as we proceed from north to south. On the other

hand, the difference between the phase lags for Ketchikan and San Francisco is considerable and hardly to be expected from the difference in latitude. As, moreover, the amplitudes are slight, it is probable that the values are influenced by some disturbing feature. Taking the average phase lag on the east coast of the Pacific to be 87° and estimating the corresponding average value for the west coast at 162°, we get a difference of 75°. As the difference in longitude between the two groups of stations is, on an average, 97°, we note that in this case also the variation in phase lag is of the same magnitude as the difference in longitude.

In addition, as far as the two hemispheres are concerned, conditions in the Pacific show a marked correspondence with those in the Atlantic. The phase-lag difference between Aikawa and Sydney is 175°, which indicates that the oscillation is practically opposite at these stations.

The remaining Ocean, the Indian, contains four stations, all of them based on at least two complete series of observations. In spite of this, owing to the position of the stations, it is difficult to draw any general conclusions. The differences in phase lag are not great, but they seem to indicate a retardation of the 18·6-year component from west to east. Amplitudes in the Indian Ocean are, as a rule, smaller than in the other oceans.

Summary

In the present paper an attempt is made to describe the regional distribution of the 18·6-year oscillation occurring in sea-level in the oceans. The results obtained seem to indicate that the difference in phase lag for stations situated approximately in the same latitude, but on opposite coasts of an ocean, is of the same magnitude as the difference in longitude. Moreover, a comparison of the results for stations in latitudes 30°–40°N. and 30°–40°S. in the same part of an ocean shows that the oscillation is practically opposite.

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The Role of Lateral Eddy Diffusion in the Northern North Sea

By

John H. Steele

Introduction

In a previous paper (STEELE, 1956), the effects of vertical mixing on plant production were investigated at one position in the centre of the northern North Sea. It was suggested that the horizontal water changes near this position could be explained in terms of lateral diffusion.

The extension of these production studies to cover the whole of the northern North Sea required a corresponding extension in the hydrography. In particular, some understanding of the relation between vertical and lateral changes was desirable. In an attempt to obtain this the data have been interpreted in the light of theories of eddy diffusion.

There is a very great mass of hydrographic data available for the northern North Sea together with a number of published studies. Probably the two most important syntheses of this information are by BÖHNECKE (1922) and TAIT (1937). Both writers were concerned with charting the surface currents, the first on the basis of salinity distribution, the second by the use of drift-bottle returns.

In this paper it is hoped to extend this earlier work slightly by suggesting a hydrodynamical analogy for the events during the period April to October in the northern North Sea.

It is a pleasure to thank Dr. TAIT for reading and criticizing this work.

Theoretical Problems

The simplest hydrodynamical approach is to neglect turbulence and assume that all water flow is along streamlines. It is on this basis that the comparatively slow and steady deep horizontal currents are calculated. It is also the basis of TAIT's drift-bottle route charts, since he postulates that

two bottles which are in the same restricted area at the same time must follow fairly similar paths (Fig. 1).

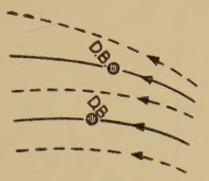

Figure 1. Paths of drift-bottles in a streamline flow.

To assume that in addition to a steady velocity, there is a random "turbulent" velocity introduces complications which are difficult to analyse. In an important paper, STOMMEL (1949) discussed the adequacy of the theories of eddy diffusion to explain events in the sea. He decided in favour of the theory involving a "spectrum of turbulence". This theory states that there is no single coefficient of eddy diffusion for a particular area at a particular time but that the coefficient varies with the scales of time and length on which it is measured. Only in this way, STOMMEL suggested, could one explain the detailed structure of the Gulf Stream, where numerous large transient eddies have been observed.

The hydrodynamical theory used here is that of the two-dimensional jet stream issuing into a motionless fluid (TOLLMIEN, 1926; GOLDSTEIN, 1938). This theory has already been used by ROSSBY (1936) to study the interchange between the Gulf Stream and its surrounding water.

Since this theory does not take account of the spectrum of turbulence it will only be relevant to conditions given by certain scales of averaging. It will be suggested that irregularities observed in particular sections across the area are similar to those found in the Gulf Stream and can be explained similarly.

Finally, because of the many other factors involved, this analogy is not intended as a full explanation but merely as an elucidation of certain features.

The Yearly Cycle in the Northern North Sea

Since it is difficult to discuss in isolation one part of a yearly cycle, a few brief remarks will be made about winter changes. These also should be considered as working hypotheses.

It is known that events in the area are dominated by the winter inflow of Atlantic water. The warm salt water enters from the Faroe-Shetland Channel round the north of Shetland, penetrating in the North Sea in a broad band stretching toward the Skagerak. It partly mixes with the water in the area and partly displaces it to the north and east, where the Baltic outflow is confined to a narrow band near the Norwegian coast.

Thus in the centre of the northern North Sea there is considerable, but not complete, mixing between the old and new water. This water is then cooled by continental influence, giving a minimum temperature about the end of March. It is this cooling which, by making the water heavier than that in the Faroe-Shetland Channel, finally ends the massive inflow.

However, due to causes outside the area, there are variations in the strength and timing of this inflow (TAIT, 1956) and these variations determine the temperature and salinity found at the end of March. For example, high salinity and low temperature in the area in March 1951 show that a large and

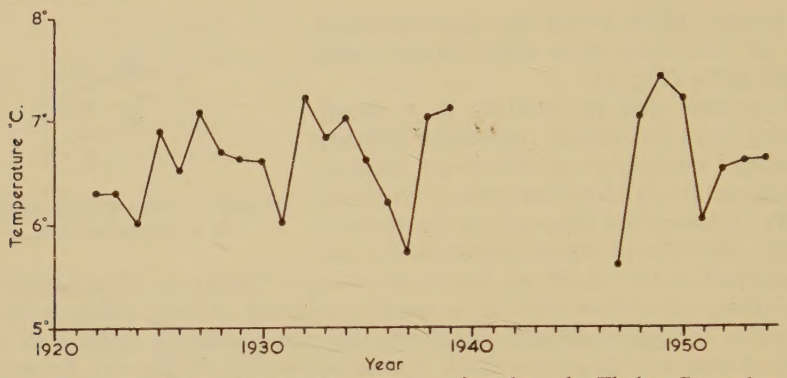

Figure 2. The near-bottom temperatures found on the Fladen Ground in spring for the years 1922–54.

early inflow occurred. The variations in salinity and especially temperature are less within any year than between years. As one index of these annual variations the bottom temperatures on Fladen for the years 1922–54 are shown in Figure 2.

Thus in March there is a body of water occupying the northern North Sea as far as the edge of the Norwegian Deep, vertically homogeneous and nearly so laterally. From this time onwards until late autumn the water below the thermocline in the centre of this area retains the same characteristics, and it is this heavy, stationary mass which prevents any general large-scale movements of the deeper water. Thus it is assumed that the water below the thermocline to the west of the prime meridian, although warmed by vertical mixing, remains relatively stationary.

For these reasons the lateral changes which occur are limited to the water above the thermocline. These changes are extensive and can be seen in the variations of surface salinity distribution (Conseil Permanent International pour l'Exploration de la Mer 1933). The low-salinity water comes from the Baltic outflow and its upper limit may be defined as the $35\,^0/_{00}$ isohaline. In the winter it is confined to a narrow band over the Norwegian Deep but later it spreads westwards, often reaching the prime meridian. It is the mechanism of this spread which is the main subject of this paper and which will be compared to the theory of a jet stream.

Briefly this theory states that when a jet issues into a motionless fluid there is turbulent mixing along its edges making the jet gradually spread out. An important feature is that as a result of this mixing, *the jet draws in fluid from its surroundings*. This intake is greatest near the apex and decreases downstream. In Figure 3 the direction of mean flow is shown, but this will not be the direction of small volumes of water which will be mixing turbulently across the stream. A cross-section of this distribution of mean flow is shown in Figure 4; the velocity along the axis decreases downstream. The theory also predicts that any property of the water ejected by the jet (e. g., temperature or salinity) will be distributed in the same manner as the mean velocity. Thus the comparison to be made is between a jet in which only half of that

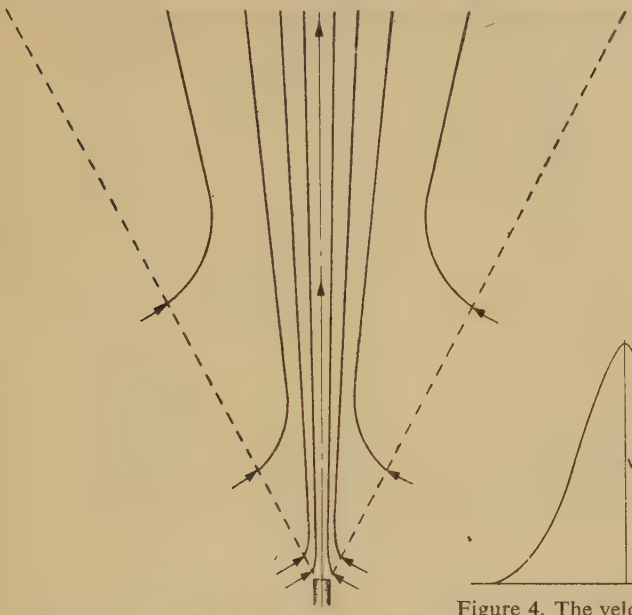

Figure 3. The lines of mean flow of a two-dimensional jet (after TOLLMIEN).

Figure 4. The velocity distribution across a section of the jet.

shown in Figure 3 is present and the Baltic current issuing from the Skagerak and kept in contact with the Norwegian coast by the clockwise action of the Coriolis force.

In Figure 3, the spread of the jet depends on the "mixing length", which, roughly, measures the ease with which lateral mixing can occur. Thus it is necessary to look for the analogy of this feature in the sea.

PARR (1936) has suggested the very reasonable hypothesis that lateral and vertical mixing are related in an inverse manner. It could be said that intense vertical mixing prevents parts of the water mass from mixing laterally. The Baltic current is confined to a surface layer and its lateral mixing depends on the structure of the water column on its western boundary.

In the winter this water to the west is homogeneous vertically and thus its vertical mixing will be at a maximum. It is for this reason that there is negligible mixing between the water masses. About mid-April, however, the thermocline begins to form and vertical mixing is reduced at this level (approximately 30 m.). The Baltic water is now free to mix with this warmer layer and it would be expected that the extent of mixing would depend on the steepness of the thermocline which increases during the summer.

It is on this basis that an expected distribution of mean flow is shown in Figure 5, where the edge of the jet, as shown by the broken line, will move westward as the summer progresses. The greatest intake of water by the Baltic current should occur south of Norway. To replace this intake, there must be a slow south-eastwards drift of the surface waters off the Scottish coast.

Figure 5. Expected distribution of mean flow in the northern North Sea.
(1) Axis of the Baltic outflow. (2) Region of lateral mixing.
(3) Induced counter-current.

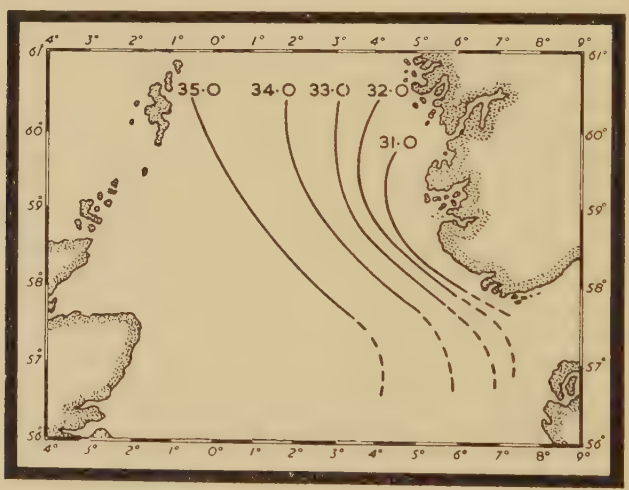

Figure 6. Expected salinity distribution derived from Figure 5.
Possible values have been put to the contours.

Figure 6 shows an approximate picture of the expected salinity distribution based on the velocity curves of Figure 5. At the point of exit of the jet, the model is unrealistic; for this reason, and since there will be other low-salinity water of coastal origin in the area, the broken lines have been drawn. The most suitable means by which this theory may be tested are the charts of mean salinity for each month prepared by the International Council for the Exploration of the Sea. These show the westward spread of the low-salinity water. In most of the summer months there is evidence for the

Figure 7. The mean distribution of surface salinity in June.

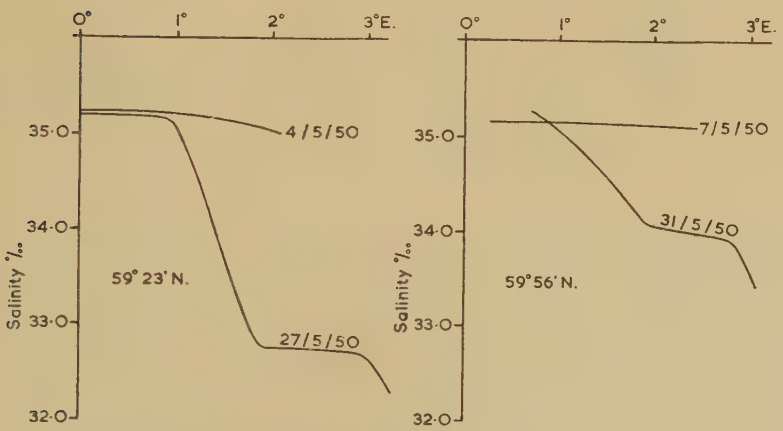

Figure 8. Surface salinity on two sections made in May 1950.

curving of the isohalines back towards the Norwegian coast; a good example of this is given in Figure 7.

This suggested model cannot be used quantitatively; the Baltic current is not constant in strength and is augmented by run-off from the Norwegian coast; the region into which it flows is not infinite[1]). Also the westward movement is not as steady as would appear from the charts of mean conditions in each month. To illustrate this point, some particular observations will be discussed.

1) The events in the southern North Sea are not considered here, but it is possible that the intake of the jet could be used as a partial explanation of water movements in this area, and in particular of the flow of water north-east from the Channel.

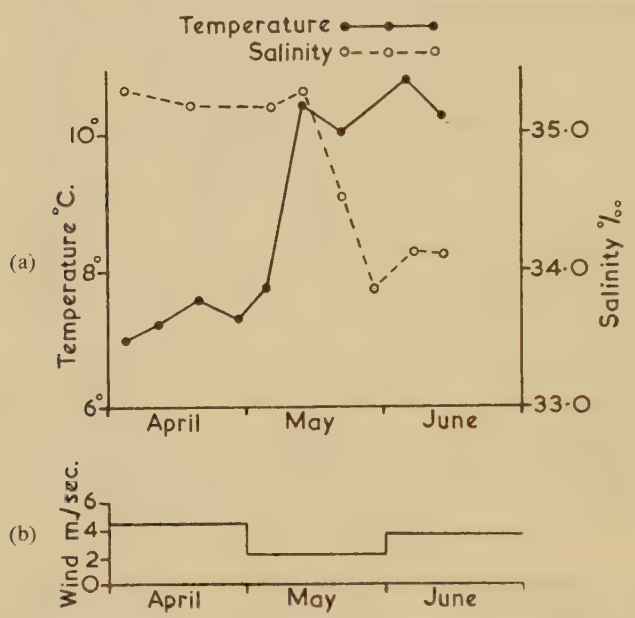

Figure 9. (a) Surface salinity and temperature at 59°52′N., 2°00′E. during part of 1950. (b) Monthly mean wind for 1950 (supplied by courtesy of the German Hydrographic Institute, Hamburg).

Firstly the events of May 1950 will be considered. Between 59° and 60°N. stations were worked by F.R.S. "Explorer" near the beginning and the end of the month; also, every eight days, surface observations were made by a commercial ship at 59°52′N., 2°00′E. (*Bulletin Hydrographique*, Conseil Permanent International pour l'Exploration de la Mer, 1954). Some of these values, together with monthly mean wind data (supplied by courtesy of the German Hydrographic Institute, Hamburg) are shown in Figures 8, 9, and 10. From the "Explorer" sections (Fig. 8) it can be seen that there was an extensive spread of surface salinity in just over three weeks. To explain this one can assume that the winds (Fig. 9b), which were generally weak in this month, were exceptionally weak during the period 5.–13. May, when there was an abrupt rise in surface temperature (Fig. 9a), suggesting the formation of a very thin heated layer. Immediately after the formation of this layer the salinity at 59°52′N., 2°00′E. began to drop sharply, implying that this layer was mixing rapidly with the Baltic water to the east. The fact that the temperature did not increase after its initial jump suggests that there was some downwards mixing before the conditions of 27. May were reached (Fig. 10).

As a second example, let us consider the expected salinity distribution along a section near 60°N. It should have the form shown in Figure 11, and the average of many observations confirms this. However, individual sections show marked variations. The previous example is one case, but to

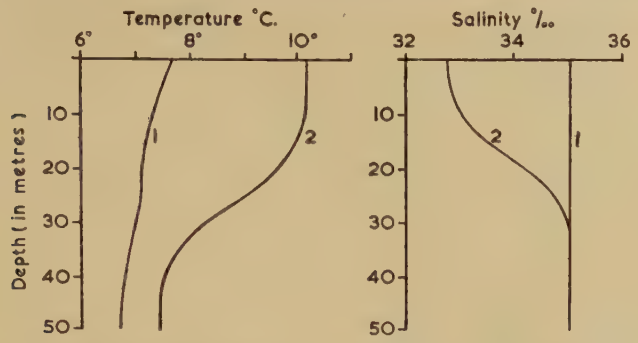

Figure 10. Temperature and salinity at (1) 59°23′N., 2°05′E. on 4. May and (2) 59°23′N., 1°54′E. on 27. May 1950.

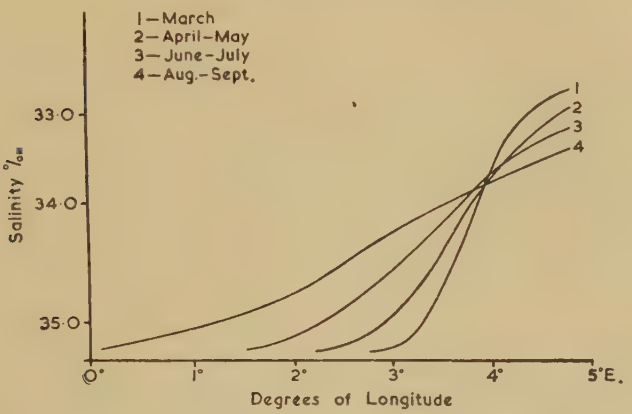

Figure 11. Probable changes in salinity distribution along a section near 60°N.

extend this, the surface salinities from a set of sections worked in June 1954 are given in Figure 12. It is obvious that this is not a gradual mixing process and the only satisfactory explanation is to suppose that the mixing of the Baltic water begins with the shearing-off of comparatively large eddies. These eddies are transient and break down to smaller and smaller eddies. It is this mechanism which STOMMEL describes in terms of a "spectrum of turbulence".

A further factor which cannot be ignored is wind stress at the sea surface. However, the fact that the spread of low-salinity water is in the opposite direction to the prevailing winds implies that their effect is not predominant. The wind may act by stemming the spread, and variable wind strengths may produce variations in the westward movement.

On the other hand, one main deduction from this analogy is that steepness of the thermocline controls this spread and this is related to the winds through the action of gales (STEELE, 1956, p. 14). Some support for the idea

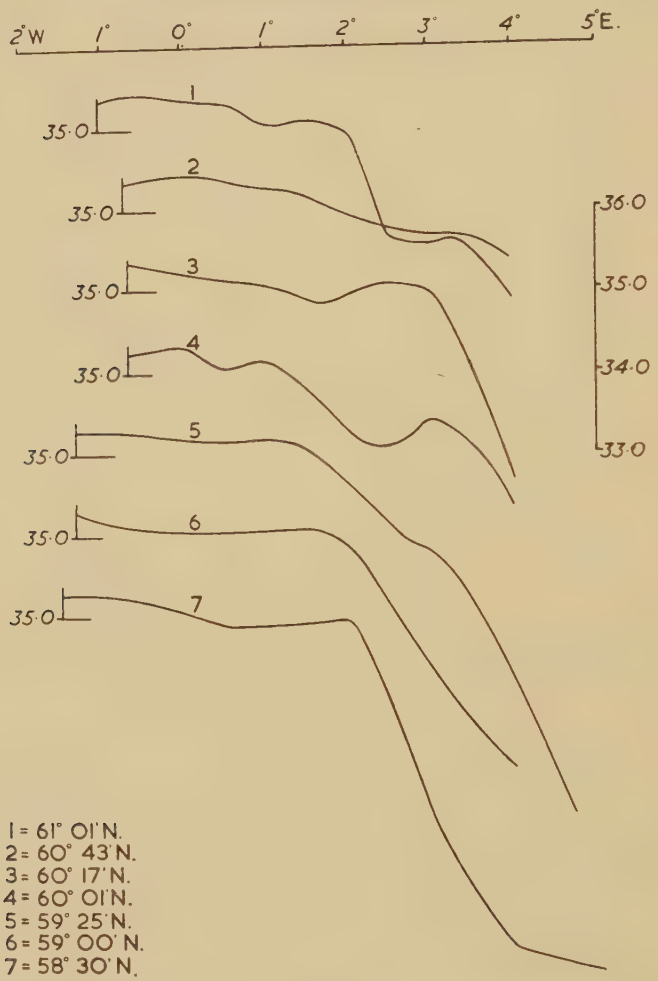

Figure 12. Salinity distributions along sections across the North Sea in June 1954.

of this mode of control was obtained in the following way. For the years 1922–53 all available stations in the area 58° to 60°N., 0° to 1°E. in the month of July were used. For each year the mean surface salinity and the mean of the greatest temperature change in 10 metres were calculated. The negative correlation between these figures was significant at the 1% level. As an index of this variation, the salinity values are given in Figure 13.

During this period the only function of the Atlantic influence was to replace water removed by jet action. This must have produced some surface inflow around Shetland but it should be emphasized that one of the main implications of this theory is that the inflow is very small compared with the

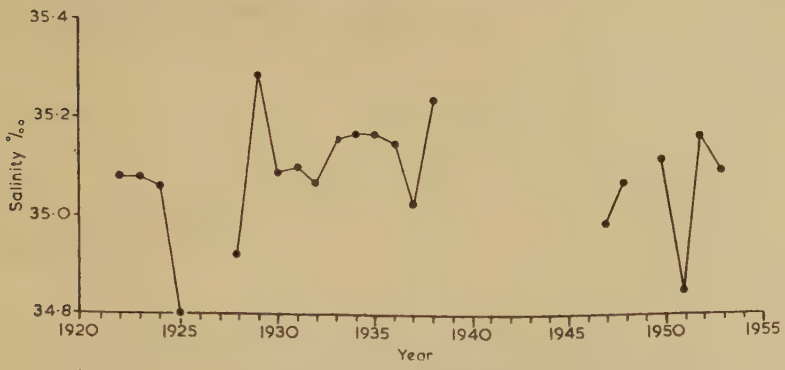

Figure 13. Mean surface salinity in the area 58° to 60°N., 0° to 1°E. during July for the years 1922–53.

volume that enters during the winter, and also that the mechanisms are very different.

Just as in spring the creation of the thermocline produced the Baltic spread, so in the autumn the breakdown of the thermocline ends it.

By decreasing the density of the lower waters, the breakdown makes them comparable with the Atlantic Current around the north of Shetland. As a result of tidal effect, this occurs first in the shallower waters between the Scottish coast and the prime meridian. Thus at the end of September, this water could be displaced, were it not for the still cold central mass which blocks its escape.

The breakdown of the thermocline in the centre of the northern North Sea is determined by the relative effects of two factors — cooling and wind. Cooling alone causes a slow breakdown that might not be complete till late November. The gales that occur from the equinox onwards hasten this process. Their effect can be seen by the fact that when the breakdown is occurring there is an increase in the total heat content of the water column. This factor is variable from year to year and so varies the date of final breakdown which can occur at any time from mid-October onwards. When this happens large-scale movements are again possible and the cycle begins again.

Summary

An attempt is made to interpret the hydrography of the northern North Sea from the standpoint of the possible effects of lateral eddy diffusion.

It is suggested, firstly, that the events in summer and winter must be considered as having different characteristics, in that: —

a) during winter, water movements cause changes throughout the water column whereas in summer the main changes occur above the thermocline, and
b) in winter the Atlantic inflow is the dominating feature, but in summer it is the Baltic outflow that mainly generates upper-water movement.

Secondly, it is proposed that the action of the Baltic outflow can be compared with the theory of the two-dimensional jet stream and this analogy elucidates the following features: —

a) the westward spread of Baltic water during the summer and the average salinity patterns resulting from this,
b) year-to-year variations in the extent of this spread, and
c) the south-east drift of water off the Scottish coast, resulting from intake by the jet.

Finally, the suggestion is made that irregularities in particular salinity distributions can be explained in terms of a spectrum of turbulence.

Such an approach does not greatly alter the general distribution of surface currents suggested by TAIT, but it is hoped that it may provide some insight into the mechanisms by which these currents arise and into the relations between vertical and horizontal changes

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The Solubility of Oxygen in Saline Water

By

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Introduction

In the work on the solubility of oxygen in water reported recently by TRUESDALE, DOWNING, and LOWDEN (1955), only one of the measurements made in saline water was for a temperature of less than 6·5°C. Since the solubility of oxygen at the lower temperatures is of considerable interest to marine research workers it was thought advisable to check the validity of the solubility formula that had been derived; consequently a further four determinations have been made in sea water below 7°C. One determination in pure water at 0°C. has also been made.

Experimental

The apparatus and the experimental techniques were similar to those used in the original work; in this method the water is slowly stirred to bring it into equilibrium with a constantly replenished atmosphere of filtered air from which carbon dioxide has been removed and which has been saturated with water vapour. The water was stirred at 38 r. p. m. by a constant-speed electric motor. The sea water for the experiments was collected from the English Channel near Plymouth; before use, it was treated — in the manner previously described — to eliminate the biochemical oxygen demand, and was then diluted to the required salinity with sterile distilled water. The pure water used in the one experiment had a conductivity of 1·0 μmho per cm.

Results

The results of the five measurements are given in Table 1, where they are compared with the values calculated from the published equation[1])

$$C'_s = 14{\cdot}161 - 0{\cdot}3943T + 0{\cdot}007714T^2 - 0{\cdot}0000646T^3 - S(0{\cdot}0841 - 0{\cdot}00256T + 0{\cdot}0000374T^2) \text{ mg. per litre} \qquad (1)$$

[1]) This equation was incorrectly given on p. 266 of Vol. **21**, 3 of this journal (TRUESDALE and KNOWLES, 1956).

Table 1

Comparison between observed values of solubility with those given by Equation 1

Temperature °C.	Salinity ‰	Solubility (mg. per litre) Observed C_s	Calculated C'_s	Difference $C_s - C'_s$
0·0	0	14·17	14·16	0·01
—1·5	30·1	12·12	12·12	0·00
0·0	30·1	11·69	11·63	0·06
3·15	30·1	10·70	10·70	0·00
6·5	34·8	9·51	9·51	0·00

where C'_s is the saturation concentration of oxygen in water of salinity S‰ (g. per 1000 g.) and temperature T°C., when the total pressure of air — saturated with water vapour — is 760 mm. of mercury. In the table the observed values have been adjusted for the barometric pressure measured at the time of the experiments.

The differences shown in the last column of Table 1 are all within the limits of experimental error and there is nothing to be gained by taking together all the available data to produce a new solubility formula differing very slightly from Equation 1. The root-mean-square deviation of the total of 53 observed values from those given by the equation is 0·04 mg. per litre. These observed values comprise 30 in fresh water at temperatures ranging from 0° to 39·2°C., 20 in sea water from —1·5° to 35·4°C., and 3 in water of intermediate salinity from 5·5° to 30·1°C.

It seems reasonable to conclude that Equation 1 gives the solubility of oxygen in water with a salinity from 0 to 35‰ to within 0·1 mg. per litre of the true value, from the freezing point to at least 35° and probably to 40°C. The accuracy of the equation is likely to be very much better than this over most of the range.

Solubility in Sea Water

Equation 1, while expressing the experimental results with considerable accuracy, is inconvenient to use whenever a figure for the solubility in sea water is required. Accordingly the solubilities in sea water of salinity 35‰ have been tabulated, at intervals of 0·1°C., from —2° to 40°C. (Table 2). For salinities other than 35‰ the solubility is readily found by means of the final column of the table, which shows the change in solubility for a change of 1‰ in salinity. As an example of the application of this table, we may consider the experiment summarized in the fourth line of Table 1. Interpolating in Table 2 between 3·1° and 3·2°C., we find that the solubility at 3·15°C. and 35‰ salinity is 10·32 mg. per litre; from the final column it is seen that an increase in salinity by 1‰ is accompanied by a decrease of 0·076 mg. per litre in the solubility, so the required figure is $10{\cdot}32 + 4{\cdot}9 \times 0{\cdot}076$, or 10·69 mg. per litre. The discrepancy of 0·01 between this figure and the one given in Table 1 is a rounding-off error.

Table 2

Solubility of oxygen in sea water of salinity 35 $^0/_{00}$, in mg. per litre, from a normal atmosphere saturated with water vapour at a total pressure of 760 mm. of mercury from −2 to +40°C. $\triangle C_1$ is the change in solubility for a change of 1 $^0/_{00}$ in salinity

Temp. °C.	·9	·8	·7	·6	·5	·4	·3	·2	·1	·0	$\triangle C_1$
—2										11·86	
—1	11·82	11·79	11·76	11·72	11·69	11·66	11·63	11·59	11·56	11·53	—0·088
—0	11·50	11·47	11·44	11·41	11·37	11·34	11·31	11·28	11·25	11·22	—0·085

Temp. °C.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	$\triangle C_1$
+0	11·22	11·19	11·16	11·13	11·10	11·07	11·04	11·01	10·98	10·95	—0·083
1	10·92	10·89	10·86	10·83	10·80	10·78	10·75	10·72	10·69	10·66	—0·080
2	10·64	10·61	10·58	10·55	10·52	10·50	10·47	10·44	10·41	10·39	—0·078
3	10·36	10·33	10·31	10·28	10·26	10·23	10·20	10·18	10·15	10·12	—0·076
4	10·10	10·07	10·05	10·02	10·00	9·97	9·95	9·92	9·90	9·87	—0·073
5	9·85	9·82	9·80	9·78	9·75	9·73	9·70	9·68	9·66	9·63	—0·071
6	9·61	9·58	9·56	9·54	9·52	9·49	9·47	9·45	9·42	9·40	—0·069
7	9·38	9·36	9·33	9·31	9·29	9·27	9·25	9·22	9·20	9·18	—0·067
8	9·16	9·14	9·12	9·10	9·07	9·05	9·03	9·01	8·99	8·97	—0·065
9	8·95	8·93	8·91	8·89	8·87	8·85	8·83	8·81	8·79	8·77	—0·063
10	8·75	8·73	8·71	8·69	8·67	8·65	8·63	8·61	8·59	8·58	—0·061
11	8·56	8·54	8·52	8·50	8·48	8·46	8·45	8·43	8·41	8·39	—0·059
12	8·37	8·36	8·34	8·32	8·30	8·29	8·27	8·25	8·23	8·22	—0·058
13	8·20	8·18	8·17	8·15	8·13	8·12	8·10	8·08	8·06	8·05	—0·056
14	8·03	8·02	8·00	7·98	7·97	7·95	7·94	7·92	7·90	7·89	—0·055
15	7·87	7·86	7·84	7·83	7·81	7·80	7·78	7·76	7·75	7·73	—0·053
16	7·72	7·70	7·69	7·67	7·66	7·65	7·63	7·62	7·60	7·59	—0·052
17	7·57	7·56	7·54	7·53	7·52	7·50	7·49	7·48	7·46	7·45	—0·051
18	7·43	7·42	7·41	7·39	7·38	7·37	7·35	7·34	7·33	7·31	—0·049
19	7·30	7·29	7·27	7·26	7·25	7·23	7·22	7·21	7·20	7·18	—0·048
20	7·17	7·16	7·15	7·13	7·12	7·11	7·09	7·08	7·07	7·06	—0·047
21	7·05	7·03	7·02	7·01	7·00	6·99	6·97	6·96	6·95	6·94	—0·046
22	6·93	6·92	6·90	6·89	6·88	6·87	6·86	6·85	6·84	6·82	—0·045
23	6·81	6·80	6·79	6·78	6·77	6·76	6·75	6·73	6·72	6·71	—0·044
24	6·70	6·69	6·68	6·67	6·66	6·65	6·64	6·63	6·62	6·61	—0·044
25	6·60	6·59	6·57	6·56	6·55	6·54	6·53	6·52	6·51	6·50	—0·043
26	6·49	6·48	6·47	6·46	6·45	6·44	6·43	6·42	6·41	6·40	—0·042
27	6·39	6·38	6·37	6·36	6·35	6·34	6·33	6·32	6·31	6·30	—0·042
28	6·29	6·28	6·27	6·26	6·25	6·24	6·23	6·22	6·21	6·20	—0·041
29	6·19	6·18	6·17	6·16	6·15	6·14	6·13	6·12	6·12	6·11	—0·041
30	6·10	6·09	6·08	6·07	6·06	6·05	6·04	6·03	6·02	6·01	—0·041
31	6.00	5.99	5.98	5·97	5·97	5·96	5·95	5·94	5·93	5·92	—0·040
32	5·91	5·90	5·89	5·88	5·87	5·86	5·85	5·84	5·83	5·82	—0·040
33	5·82	5·81	5·80	5·79	5·78	5·77	5·76	5·75	5·74	5·73	—0·040
34	5·72	5·71	5·70	5·69	5·68	5·68	5·67	5·66	5·65	5·64	—0·040
35	5·63	5·62	5·61	5·60	5·59	5·58	5·57	5·56	5·55	5·54	—0·040
36	5·53	5·52	5·51	5·51	5·50	5·49	5·48	5·47	5·46	5·45	—0·040
37	5·44	5·43	5·42	5·41	5·40	5·39	5·38	5·37	5·36	5·35	—0·041
38	5·34	5·33	5·32	5·31	5·30	5·29	5·28	5·27	5·26	5·25	—0·041
39	5·24	5·23	5·22	5·21	5·20	5·19	5·18	5·17	5·16	5·15	—0·041
40	5·14										

Simple Formulae for the Solubility

It is sometimes convenient to use a solubility formula that is simpler than Equation 1, though of less wide application; such a formula is that of GAMESON and ROBERTSON (1955)

$$C_s' = \frac{475 - 2{\cdot}65S}{33{\cdot}5 + T} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where the symbols and units are the same as in Equation 1. For fresh water the two equations differ by less than 0·04 mg. per litre in the range 0° to 29°C.; for water of salinity 35 ‰ the difference is less than 0·05 mg. per litre in the range 9° to 24°C., and less than 0·08 mg. per litre from 6° to 40°C.

A rather more accurate formula is

$$C_s' = \frac{475 - (2{\cdot}83 - 0{\cdot}011T)S}{33{\cdot}5 + T} \quad \ldots\ldots\ldots\ldots \quad (3)$$

For fresh water this equation is identical with the previous one, but at salinity 35 ‰ it differs from Equation 1 by less than 0·06 mg. per litre from —2° to 35°C. and by not more than 0·04 mg. per litre from —1·5° to 34°C.

Acknowledgements

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Synopsis

Four determinations of the solubility of oxygen in sea water at low temperatures have been made; the results confirm the accuracy at such temperatures of a solubility formula previously reported. A table of solubilities in sea water is given, and the uses and limitations of some solubility formulae are discussed.

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Factors Affecting the Accuracy of Thermometric Depth Determinations

By

G. G. Whitney, Jr.

A point in oceanography upon which a considerable difference of opinion appears to exist is the accuracy of depth measurements made by the use of deep-sea reversing thermometers. The perhaps over-optimistic view taken by some observers is that such thermometers are absolutely reliable, and that depth determinations made in this manner are accurate to the last metre. At the other extreme are those who prefer to trust their meter wheel, trigonometry, and strain calculations to give them depths based on wire-angle and length, and are suspicious of all thermometers.

In order to attempt to clarify the issue and resolve these differences of opinion, it is proposed herein to examine the problem in some detail, and to set forth the various factors which may affect the potential accuracy of thermometric depth determinations, exclusive of mathematical errors. It is hoped that this discussion will be of benefit to those who have occasion to use one of the oceanographer's most basic tools, the reversing thermometer.

In the following paragraphs dealing with the possible sources of error, protected thermometers graduated in 0·05°C. (20 scale divisions per degree) and unprotected thermometers graduated in 0·1°C. (10 scale divisions per degree) will be used as examples. In general, if the number of scale divisions per degree is halved, the possible error will be doubled.

In common practice, the technique used in thermometric determination of depth is to pair an unprotected reversing thermometer (bulb exposed to pressure of the water) with a protected one (bulb shielded from water pressure) in the same frame on the hydrographic cable so that they are reversed simultaneously at the same depth and temperature. The actual temperature in situ (T_w) can be determined, after certain corrections, from the reading of the protected thermometer, while the actual temperature plus the effect of the water pressure at that depth (T_u) is indicated, after certain corrections, by the reading of the unprotected thermometer. The

difference between these two readings (T_u–T_w) is the result of pressure exerted on the bulb of the unprotected thermometer by the depth of the water. From laboratory tests (pressure factor determinations) prior to use at sea, the amount of increase in reading of each unprotected thermometer due to a given amount of pressure on the bulb (given depth) has been established; this being known, T_u–T_w can be translated into depth.

This pressure factor, or Q, is generally expressed in degrees Centigrade per kilogramme per square centimetre. Its magnitude will usually be between 0·0750°/Kg./cm². and 0·1250°/Kg./cm². In referring to Q, the unnecessary parts of the expression are normally omitted, so that the two noted above would be written simply ·0750 and ·1250.

When Q is large, the potential accuracy of the depth indication is also large, but the useful range of the instrument is small. If the Q of a shallow-water unprotected thermometer (range −2 to 30°C.) were as high as 0·2000 the reading increase due to pressure at 1000 metres would be of the order of 20·5°C. or 0·02° per metre. Since an instrument of this range can easily be read to the nearest 0·01°, one could theoretically detect a change of half a metre in depth, but the instrument would not be usable much below 1000 metres, as T_u would then be apt to be above the upper limit of the scale.

General practice in the manufacture of shallow-water unprotected thermometers is to attempt to achieve the largest pressure factor (for accuracy) consistent with the ability to use the instrument to depths somewhat below 2000 m. Deep-water unprotected thermometers (range −2 to 60°C.) of necessity have somewhat smaller pressure factors, of the order of 0·0800. The bulbs must have somewhat stronger walls to withstand pressure at depths down to around 6000 m., and hence respond less to a given pressure load. While these can be used at any depth down to the limit of the scale, because of their small Q and large graduation interval (0·2°), precise results are difficult to obtain. For special purposes, thermometers have been designed and built, for the Woods Hole Oceanographic Institution, which have a scale running from 35° to 60°C. (with zero point) graduated in 0·1°, and having a very small Q. These are usable only at depths below 4000 m., but are capable of a high degree of accuracy from that level down to the very deepest parts of the Atlantic Ocean, about 8000 m.

Since the Q of each unprotected thermometer depends upon the shape, size, wall thickness, and glass characteristics of the main bulb, there is no way of controlling its exact value in manufacture; Q may well vary ±0·0050 or more from the nominal value desired. For this reason, the Q for each unprotected thermometer must be determined by laboratory test.

In such tests, the unprotected thermometer is reversed at a known temperature and pressure, and the Q determined according to the formula $Q = \frac{T_u - T_w}{P}$, where T_u is the unprotected reading after application of scale correction, T_w is the actual temperature at the time of reversal, and P is the pressure expressed in Kg./cm². T_w may be determined either by immersing the pressure vessel in melting ice (0·00°C.) or by placing a protected thermometer in the pressure vessel with one or more unprotected thermometers, in which case T_w is taken as the corrected reading of the protected thermo-

meter. This latter method is employed at this laboratory, although ice is used in the water bath surrounding the pressure vessel to keep the temperature essentially level near 0°C. (WHITNEY, 1955).

Since no thermometer can be expected to show exactly the actual temperature at all points on the thermometer scale, all reversing thermometers must be calibrated to establish the required scale corrections prior to the pressure factor tests and issue for use at sea.

It is obvious, therefore, that a large number of tests and readings are necessary to certify a reversing thermometer before the oceanographer sits down to make his final temperature and depth calculations. There are discussed below the factors which may affect the ultimate accuracy of thermometric depth determinations. It will be noted that each point covered involves a possible error.

Probable Accuracy of Standard Thermometer

In order to establish the necessary scale corrections for thermometers, a temperature standard is required. At the Woods Hole Oceanographic Institution, a set of specially designed mercury-in-glass thermometers, covering several temperature ranges, are used for this purpose. These themselves require scale corrections, which have been determined by the National Bureau of Standards. Frequent checks in melting ice are made of these standard thermometers to note any shift in the reading at 0·000°C. (which would cause an equal shift in the scale corrections at all other points on the scale). It is considered that these standards, as corrected, give temperature values within $\pm$0·003°C. of the actual temperature.

Since these standard thermometers are used to determine scale corrections for both the protected and unprotected thermometers, this possible source of error must be taken into consideration twice, once for each type of reversing thermometer.

Possible Error in Thermometer Scale Corrections after Calibration

Necessary scale corrections for both protected and unprotected thermometers are determined in a controlled temperature tank. Readings of the reversing thermometers for three to five reversals at the same nominal temperature are compared with readings of the standard thermometer at those same temperatures. The arithmetical average of the indicated corrections for all tests at each nominal temperature is used as the final stated correction for the instrument at that temperature. For example, if the indicated corrections for five reversals at a given temperature were —0·045, —0·040, —0·043, —0·045, and —0·038, the final stated correction at that temperature would be —0·042°. It is considered that this final correction value will be accurate to within $\pm$0·002° if the scale is graduated in 0·05° increments (protected thermometer) or within $\pm$0·004° if the scale is graduated in 0·1° (unprotected thermometer).

Possible Interpolation Error

Reversing thermometers are usually calibrated every fifty scale divisions (every five degrees if the scale is graduated in 0·1° increments). Exceptions are those of range −2 to 8°C., which are calibrated every forty scale divisions (two degrees), and sometimes those of range −2 to 15°C., which may be calibrated every sixty scale divisions (three degrees). If the scale corrections vary greatly from one calibration point to the next, the interpolation necessary to arrive at the correction for a reading lying between two such calibration points can lead to a very substantial error, as there is no way of knowing that the correction change is linear between the two points. If the rate of change of corrections is less than 0·1 scale division per degree (as usually specified), the interpolation error in applying scale corrections to readings of the unprotected thermometers during pressure factor tests should not be more than ±0·004°. Since these Q tests are made at temperatures approximating to 0°C., the known 0° correction of the protected thermometer used as a standard is applied, and no interpolation is necessary, so no error should exist from this source.

Possible Reading Error during Q Tests

Even the eye of an experienced technician may, on occasion, make minor errors in reading the thermometers during Q tests. Fogging and parallax are frequently encountered. While errors of this nature will generally average out, they may not, and this possible error must be taken into consideration. Such reading error might be ±0·002° for the protected thermometer (pressure standard), and ±0·004° for the unprotected thermometers.

If the total amount of the possible errors noted so far are added, the sum is ±0·022°, the probable accuracy of the thermometer as ready for use at sea.

Inherent Accuracy of Thermometer

The heart of any reversing thermometer is its break-off point, the junction of the main capillary bore with the so-called appendix, or "dead arm", at which point the mercury column is supposed to separate when the instrument is reversed. The precision and care with which this break-off point is made determines the inherent accuracy or reproducibility of the thermometer. A good instrument should be able consistently to reproduce readings at the same temperature to within ±0·1 scale division (within ±0·005° for a protected thermometer graduated in 0·05°; within ±0·01° for an unprotected thermometer graduated in 0·1°). Some of the very best instruments will reproduce to within less than half these limits, but the larger figures should be used in considering possible errors.

Possible Reading Error at Sea

When the thermometer is used at sea, some of the same sources of error are again present, so that additional errors may be introduced at each

Sources of Error in Thermometric Depth Determinations

	Affecting protected thermometres		Affecting unprotected thermometres	
Probable accuracy of standard thermometer, as corrected	0·05° graduations ±0·003°C.	0·1° graduations ±0·003°C.	0·1° graduations ±0·003°C.	0·2° graduations ±0·003°C.
Possible error in thermometer scale corrections after calibration.....	0·002	0·004	0·004	0·008
Possible interpolation error in correcting thermometers during *Q* tests (may be much greater if rate of change of scale corrections is large)	None	–	0·004	0·008
Possible reading error during *Q* tests	0·002	–	0·004	0·008
Probable inherent accuracy of thermometers	0·005	0·010	0·010	0·020
Possible reading error at sea	0·005	0·010	0·010	0·020
Possible interpolation error in correcting thermometers (may be much greater if rate of change of scale corrections is large).....	0·002	0·004	0·004	0·008
Possible errors in rounding scale corrections to nearest 0·01°	0·005	0·005	0·005	0·005
Total possible error.....	±0·024°C.	±0·036°C.	±0·044°C.	±0·080°C.

Total possible error of column 1 paired with column 3..... ±0·068
Total possible error of column 2 paired with column 3..... ±0·080
Total possible error of column 1 paired with column 4..... ±0·104

hydrographic station. Conditions for reading the thermometers at sea are frequently far from ideal, and it may be expected that reading errors of ±0·005° for the protected, and ±0·01° for the unprotected thermometers may commonly occur.

Possible Interpolation Errors in Correcting Thermometers

Since readings at sea seldom come at points of known correction on the scale (calibration points), interpolation of the scale corrections must usually be made. If the rate of change of scale corrections is small, as mentioned above, the possible interpolation error might be ±0·002° for the protected thermometer and ±0·004° for the unprotected thermometer. As stated previously, if the rate of change of scale corrections is large, these interpolation errors may be very much greater.

Possible Error in Rounding-off Scale Corrections

To simplify the final calculation of temperature and depth, scale corrections which are stated to the nearest 0·001° are commonly rounded to the nearest 0·01° (−0·034 becomes −0·03; −0·035 becomes −0·04). In this way, additional error in each thermometer may be introduced up to ±0·005°.

Summation of Possible Errors

If all of these possible errors are added together, the result is a total of $\pm 0{\cdot}068$ (see table). If Q is large (i. e., 0·1250) this would result in a possible error in depth of $\pm 5{\cdot}4$ m. per 1000 m., or $0{\cdot}54\%$. If Q were small, (i. e., 0·0750) the error might be $\pm 0{\cdot}91\%$. It is most unlikely that all errors would be in the same direction in any given case, so the accuracy should generally be much better than this.

If an unprotected thermometer graduated in 0·2° is used, the total possible error might be increased by $\pm 0{\cdot}036°$, or about 53% more error than shown in the table. If a protected thermometer graduated in 0·1° were used to determine T_w at sea, the total error might be increased by $\pm 0{\cdot}012°$, or 18% more than shown in the table.

Exception for Depth less than 1000 Metres

This reasoning does not, however, hold for depths between 1000 m. and the surface. The nature of the depth calculation is such that at these shallower depths, errors in reading and in the apparent accuracy of the thermometers become increasingly more significant at a rapid rate as one approaches the surface. In addition, tests tend to indicate that the pressure factor of many unprotected thermometers becomes unreliable, and may change 0·0003 or more at depths less than 500 m.; in other words, it becomes inconstant at low pressure.

WÜST (1932) made an extensive examination of this matter in connexion with the thermometers used by the "Meteor" Atlantic Expedition, for which he assumed a general average value of the pressure factor of 0·0900. He concluded that the maximum probable error of depth determination might be $\pm 1{\cdot}0\%$ at 5000 m., $\pm 1{\cdot}4\%$ at 1000 m., and $\pm 6{\cdot}0\%$ at 100 m. He also postulated that the mean accuracy might be expected to be $\pm 0{\cdot}4\%$ at 5000, $\pm 0{\cdot}6\%$ at 1000, and $\pm 3{\cdot}0\%$ at 100 m.

If the same relation of probable maximum to probable mean accuracy used by WÜST is applied to the estimated maximum probable errors stated above and shown in the table, the resulting probable mean errors would be $\pm 0{\cdot}23\%$ if Q were large, or $\pm 0{\cdot}38\%$ if Q were small, at depths of about 1000 m. These percentages would decrease slightly at greater depths, and increase considerably toward the surface.

It may be noted that WÜST attributed a rather large error, $\pm 0{\cdot}0006$, to the pressure factor. Recent investigation tends to indicate that, at depths of around 1000 m. and greater, the pressure factor can generally be expected to be accurate to within $\pm 0{\cdot}0001$. On the other hand, considering the many possible sources of very minor errors arising in the calibration of the reversing thermometers and their reading and correction at sea, as shown in the table, WÜST's estimate of errors attributable to reading and correction (ΔT) of $\pm 0{\cdot}04°$–$0{\cdot}05°$ maximum, or $\pm 0{\cdot}02°$ mean, was perhaps on the conservative side. Although WÜST considered the possible error of ϱ m. in his calculations, this is so small, except at the very shallowest depths, that for all practical purposes it may be disregarded.

Conclusion

It is perhaps interesting to note the relative similarity of the ultimate conclusions reached by WÜST and in the present work with different lines of reasoning.

All of the foregoing assumes that instruments of good quality, which have been carefully calibrated, are used by competent observers, and that functioning of the thermometers is normal. Major malfunctions, in which the thermometer reads incorrectly by upwards of a degree or more, are relatively easy to detect. Minor malfunctions, in which the reading is wrong by a few hundredths or tenths of a degree frequently are not apparent, and result in false temperatures and/or depths. Malfunctions of this sort may be considered responsible for much of the criticism of the accuracy of reversing thermometers. From the same standpoint, unreliable thermometers are a serious handicap to oceanographers, so the very best instruments obtainable should be well worth the investment.

On the basis of the present work, it is therefore concluded that thermometric depth determinations are usually accurate to within 5 m. per 1000 m., and if the best instruments are used under good conditions, it would not be unreasonable to expect an accuracy to within 2 m. per 1000 m.

Summary

The technique of thermometric depth determination is briefly described, with comments on design factors affecting the magnitude of the pressure factor Q. The technique of laboratory tests of pressure factor determination is briefly described.

A detailed analysis of the nature and magnitude of the various possible sources of error involved in the calibration, pressure factor determination, reading, and correction of protected and unprotected deep-sea reversing thermometers leads to the conclusion that the accuracy of thermometric depth determinations is usually within 0·5%, and is frequently within 0·2%.

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A Modification of the Knudsen Method for Salinity Determination

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Prior to 1955 the conventional Mohr titration for chlorides was in use at the Pacific Oceanic Fishery Investigations laboratory in conjunction with Knudsen's methods for sea-water analysis (Oxner, 1946). In general, reproducibility at the end point was within the range of 0·05% to 0·1% when determinations were made by a skilled operator. Although this degree of precision is considered adequate for the needs of this laboratory, there are limitations to the method.

The Mohr method, as applied to sea water, involves reducing titration time by choosing an empirical and transitory end point in place of a stoichiometric one. As a result, the titration is highly sensitive to changes in such elements of the technique as rate of mixing, velocity of titrant addition, etc.

Another related difficulty is the gross size of the silver chloride aggregates formed during a standard Mohr titration. This heavy flock drastically reduces the surface area of the precipitate and entrains considerable quantities of the solution in the interstices, retarding the ionic exchange at the interface between silver chloride and mother liquor, and resulting in considerable end point variability. And because the Mohr end point is not permanent, a time factor, in addition to depth of colour, must be considered when determining it (U. S. Navy Hydrographic Office, 1949). Thus the entire operation falls into the category of an art, and coping with so many variables taxes the abilities of even skilled analysts.

A third factor is the sensitivity of the end point. The colloidal aggregates of silver chloride partially obscure the initial development of indicator colour, and the re-solution of silver chromate precipitated by local excesses of titrant proceeds somewhat slowly (Kolthoff and Sandell, 1949). The over-all effect, then, is a loss of indicator sensitivity.

It was felt that on theoretical grounds most, if not all, of the above-mentioned difficulties would be eliminated by the use of adsorption indicators, such as di-chlorofluorescein, in the presence of a protective colloid, as used by FAJANS (cf. TREADWELL and HALL, 1948). Adsorption indicators are organic dyes which are adsorbed on the surface of silver-chloride suspensoids on which the adsorbed Cl^- ion has been replaced by the Ag^+ ion. It is believed that such dyes owe their characteristic colour to the frequency at which the chromophoric group resonates in the molecular system (BREWSTER, 1953) and that a change in potential external to the molecule (such as occurs at a precipitometric end point) modifies the frequency of resonance and imparts a change in colour to the dye.

Adsorption indicators require a protective colloid (such as starch) to inhibit flocculation of particulate silver chloride. This increases the solid-liquid interface enormously, facilitating ionic exchange and resulting in a non-fading end point. The colour change takes place on the surface of every dispersed silver-chloride particle, thus increasing the sensitivity markedly. It must be remembered, however, that the photo-chemical reduction of ionic silver is accelerated by the sensitizing effect of the dyes (KOLTHOFF and STENGER, 1947).

Apparently there was little or no interest in FAJANS's method among early investigators in the field of marine chemistry. SARUHASHI (1953) reports a micro-method using uranin (di-chlorofluorescein), which has a mean deviation of 0·01 $^0/_{00}$ on a 1·5 ml. sample. More recently, however, COX (1954) adapted the method to the determination of salinity in sea water. He used sodium salt of fluorescein and starch as a protective colloid and reported a noticeable increase in precision over the Mohr method. Previous investigators have stressed the fact that the colour change must take place near the stoichiometric end point. However, considering the flexibility of the Knudsen technique, I believe that this is an unnecessary limitation. A series of experiments was undertaken with the following dyes: —

1. Fluorescein
2. Di-chlorofluorescein
3. Indigo disulphonate
4. Brilliant yellow
5. Tropeolin 000 (orange 1)
6. Bromophenol blue
7. Nile blue
8. Alizarin red S. (Alizarin mono sodium sulfonate)
9. Phenosafranin (after BERRY and DURRANT, 1933, quoted by KOLTHOFF and STENGER, 1947)

Most of the above compounds can be used in the determination of salinity, but all except phenosafranin have undesirable characteristics. The fluorescein dyes and brilliant yellow were rejected because of instability in contact with starch solution over long periods of time. Indigo disulphonate changes from blue to colourless and is not adsorbed on the micelles. Techniques using bromophenol blue (TREADWELL and HALL, 1948, quoting KOLTHOFF) are somewhat involved. Resonance excitation in nile blue takes place too far from the stoichiometric end point. Alizarin red S., when adjusted to the proper pH, gives a distinct colour change close to the stoichiometric end point. It is relatively stable in preserved starch solution, and with care and skill maximum stirring speed can be used throughout the titration. However,

the dye is slightly unstable in sea water and approximately 10 minutes' contact with sea water prior to titration results in etiolation of the end point.

Phenosafranin[1]) was the best among those considered in stability, sharpness of end point, and degree of contrast between the two colour phases. It is less sensitive to pH changes and more stable in sea water than Alizarin red S. and appears to be in all respects eminently suited to salinity analysis. The indicator solution is prepared in the following manner: —

1. To 700 ml. of distilled water add 1 g. of sodium benzoate, U. S. P. powder.
2. Bring solution to a vigorous boil.
3. Triturate 40 g. of soluble starch to a very thin paste with cold distilled water.
4. Slowly add the cold starch suspension to the boiling benzoate solution.
5. Continue to boil for 2 to 5 minutes after addition of starch solution.
6. Remove from heat and filter while hot through glass wool and cotton.
7. To 50 ml. of cold distilled water add 2·5 g. of phenosafranin[2]) dye. Stir thoroughly and then add the suspension slowly to the hot starch solution.
8. Mix well, and when partially cooled make up to 1,000 ml. volume with distilled water. Use 1 ml. per determination.
9. To each sample add a minimum of 10 ml. of chloride-free distilled water, to inhibit foaming.

As a further refinement the end point has been made virtually insensitive to fluctuations in quality of ambient light by the following techniques: —

1. The immediate titration area is flooded as much as possible with fluorescent light.
2. One half of the outer wall surfaces of titration beakers are painted with white enamel.
3. Light from a Bausch and Lomb spherical microscope lamp is beamed horizontally through the unpainted portion of the titration beaker and at a level of approximately 1 inch above the maximum height of liquid. Thus, the upper surface of the solution is bathed completely in diffuse light. (Any *white* light of sufficient intensity and delivered horizontally is satisfactory.)

We have found that the use of such techniques facilitates detection of the end point and markedly decreases the influence of external fluctuations in light quality, in both MOHR's and FAJANS's methods.

Routine determination follows the Knudsen method, with the exception

[1]) The adsorption behaviour of phenosafranin apparently differs from the classical concept of such indicators wherein adsorption takes place at the equivalence point simultaneously with the change in indicator colour (BREWSTER, 1953). Evidence indicates that phenosafranin is adsorbed in its primary colour phase (pink) as rapidly as silver-chloride micelles are formed. The secondary phase (blue) appears at the equivalence point subsequent to adsorption.

[2]) Phenosafranin (3, 6 di-amino-phenyl-phenazine chloride) is a biological stain and photographic anti-fog. It is manufactured by the Analine Division of Allied Chemical & Dye Corporation, N.Y., color index #840, catalogue #NA–685.

Table 1

Comparative performance data, Mohr method *versus* modified Fajans method

	Mohr Method				Modified Fajans method			
	Titration (double millilitres)	Alpha	k	Cl ‰	Titration (double millilitres)	Alpha	k	Cl ‰
Copenhagen water (19·379‰)	19·326	–	–	–	–	–	–	–
–	19·328	–	–	–	–	–	–	–
–	19·321	–	–	–	–	–	–	–
Average	19·325	+0·054	–	–	–	–	–	–
Copenhagen water (19·375‰)	–	–	–	–	19·338	–	–	–
–	–	–	–	–	19·339	–	–	–
–	–	–	–	–	19·331	–	–	–
Average	–	–	–	–	19·336	+0·039	–	–
Sea water A	19·301	–	–	–	19·324	–	–	–
–	19·300	–	–	–	19·326	–	–	–
–	19·301	–	–	–	19·321	–	–	–
–	19·302	–	–	–	19·322	–	–	–
–	19·306	–	–	–	19·322	–	–	–
–	19·301	–	–	–	19·322	–	–	–
–	19·306	–	–	–	19·321	–	–	–
–	19·310	–	–	–	19·331	–	–	–
–	19·301	–	–	–	19·326	–	–	–
–	19·305	–	–	–	19·331	–	–	–
Average	19·303	–	+0·06	19·36	19·325	–	+0·04	19·37
Mean deviation	0·0027	–	–	–	0·0032	–	–	–
% deviation	0·014%	–	–	–	0·016%	–	–	–
Sea water B	18·908	–	–	–	18·930	–	–	–
–	18·913	–	–	–	18·929	–	–	–
–	18·912	–	–	–	18·931	–	–	–
–	18·906	–	–	–	18·941	–	–	–
–	18·918	–	–	–	18 929	–	–	–
–	18·905	–	–	–	18·931	–	–	–
–	18·921	–	–	–	18·937	–	–	–
–	18·915	–	–	–	18·929	–	–	–
–	18·907	–	–	–	18·936	–	–	–
–	18·918	–	–	–	18·931	–	–	–
Average	18·912	–	+0·06	18·98	18·932	–	+0·05	18·98
Mean deviation	0·0047	–	–	–	0·0032	–	–	–
% deviation	0·025%	–	–	–	0·017%	–	–	–
Sea water C								
Operator # 1	19·292	–	–	–	–	–	–	–
–	19·291	–	–	–	–	–	–	–
–	19·291	–	–	–	–	–	–	–
Average	19·291	+0·054	+0·06	19·35	–	–	–	–
Mean deviation	0·003	–	–	–	–	–	–	–
% deviation	0·002%	–	–	–	–	–	–	–
Sea water C								
Operator # 2	–	–	–	–	19·361	–	–	–
–	–	–	–	–	19·362	–	–	–
–	–	–	–	–	19·361	–	–	–
Average	–	–	–	–	19·361	—0·002	0·00	19·36
Mean deviation	–	–	–	–	0·0003	–	–	–
% deviation	–	–	–	–	0·002%	–	–	–

of the indicator. However, a few precautions must be considered. From the standpoint of speed and efficiency, particularly in routine determinations, it is desirable to maintain maximum stirring speed throughout the entire titration. In order to accomplish this, the titrant must be introduced at the extreme periphery of the rotating solution at the beaker wall. At this point the linear velocity is low enough to permit local excesses of titrant to accumulate in a thin purple streamer which precedes the final stoichiometric change. However, the onset of the end point is so sudden that, at rapid mixing speeds and maximum titrant delivery, a high degree of visual alertness is required to detect the faint streamer of colour which precedes the stoichiometric colour changes. In stead of such a technique, the solution may be titrated rapidly at a very low stirring speed until local excesses of titrant produce distinct colour changes in the solution. Stirring may then be increased to maximum and after decoloration the titration continued, dropwise at first and then with fractional drops near the end point.

Reference to the performance data (Table 1) shows that precision is comparable between the Mohr and modified Fajans methods, the two agreeing well within the limits of experimental error. The absolute accuracy of the new method as checked against Copenhagen water is certainly as good as, if not better than, the Mohr method. It should be pointed out that the titrations shown in the performance data were done with the improved lighting technique described previously. Thus, the precision indicated is greater than has been encountered in standard Mohr techniques. In spite of this improvement in the Mohr method, long-term experience with thousands of determinations performed by different operators has shown a 25% increase in output for the phenosafranin method. This is primarily due to a marked decrease in the number of faulty titrations and in the number of standardizations required. It has been shown that this method is more easily and quickly mastered by completely inexperienced personnel. Although the samples chosen for comparison in this paper differ in chlorinity by only $0{\cdot}5\,^{0}/_{00}$, practical experience at POFI has indicated that no difficulties were encountered with samples varying in solids content from $32{\cdot}5\,^{0}/_{00}$ (sea water) to $117{\cdot}9\,^{0}/_{00}$ (samples from enclosed lagoon, Laysan Island, Hawaiian archipelago).

A table of the titration characteristics of the two methods is shown below.

Standard Mohr method	Modified Fajans method
1. Empirical non-permanent end point.	1. Stoichiometric permanent end point.
2. Sensitive to rate of mixing.	2. Not sensitive to rate of mixing.
3. Colour intensity continues to increase beyond the end point if titration is continued.	3. Colour intensity remains constant beyond the end point.
4. Alpha values may vary greatly with changes in ambient-light quality.	4. Alpha values remain constant with changes in ambient light.
5. Relatively large flock which is responsible for fading end point.	5. Colloidally dispersed precipitate.

Summary

A new adsorption indicator method for determining salinity of sea water is described. Experience over a period of twelve months has shown this method to be more trouble-free than the standard Mohr method. The number of determinations per man-hour has been increased, and a general increase in precision among all workers has been noted. This has been confirmed by other workers using other organic indicators of the same general type. The table of performance data has been included, not to prove the claim for greater precision, but rather to show that *accuracy* is comparable between the two methods. The author feels that superiority in precision can be proven only by a long-term statistical analysis of routine data.

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The Determination of Organic Carbon in Marine Muds

By

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In the study of the productivity of shallow waters a knowledge of the organic-carbon content of muds is of considerable value. The determination of organic carbon may be carried out by the method of VAN SLYKE or titrimetrically by wet oxidation with chromic acid. VAN SLYKE's method has two disadvantages, firstly that carbonates must be absent or determined separately, and secondly that it requires special apparatus. The wet oxidation method is not affected by carbonates, but other reducing substances interfere. Most earlier workers have employed the method devised by SCHOLLENBERGER for the analysis of soils, in which the sample is heated for 90 seconds at 175°C. with excess chromium trioxide in concentrated sulphuric acid, and the chromic acid remaining after the reaction is determined volumetrically with ferrous ammonium sulphate solution. ALLISON has examined SCHOLLENBERGER's method and reports that the results obtained by this method must be multiplied by 1·15 in order to bring them into line with those obtained by dry combustion. WALKLEY has carried out a critical study of the determination of organic carbon in soils by chromic acid oxidation and has concluded that the greatest single cause of error is the variable nature of the organic material present.

When attempts were made to apply SCHOLLENBERGER's method to the analysis of muds, two difficulties were encountered. Firstly, the end point of the titration — a change from blue to green — was difficult to observe in the presence of suspended silt. Substitution of the ferrous-o-phenanthroline complex for the diphenylamine indicator gave an end point which was more readily seen. Secondly, samples of mud which had been ignited at 400°C., and which contained no detectable organic carbon, gave quite appreciable values for organic carbon owing to the reaction of chromic acid with the ferrous minerals present. Furthermore, the reproducibility of the method was poor (coefficient of variation ca. 20%).

Table 1

Analysis of carbonate-free muds

Sample No.	% "Carbon" found					Mean (A)	% carbon by combustion (B)	Factor B/A
27 G	0·22	0·23	0·21	0·20	0·22	0·22	0·25	1·14
31 G	0·32	0·29	0·31	0·34	0·34	0·32	0·36	1·13
61 G	0·45	0·44	0·41	0·40	0·42	0·43	0·48	1·12
23 G	0·46	0·50	0·50	–	–	0·49	0·59	1·20
63 G	0·69	0·61	0·72	–	–	0·67	0·81	1·21
12 G	1·24	1·33	1·35	–	–	1·31	1·53	1·17
22 G	4·40	4·28	4·15	4·10	–	4·34	4·59	1·06

In order to reduce interference from ferrous iron, experiments were carried out with the use of much milder and more reproducible oxidation conditions. It was found that consistent results for organic carbon in muds were obtained if the oxidation was carried out at 100°C. for 15 minutes.

Since the amount of chromic acid consumed depends on the completeness of oxidation and on the type of carbon linkages oxidized, the observed results must be multiplied by an empirical factor to bring them into agreement with the actual carbon content. To evaluate this factor a number of muds of salt-water origin were treated with dilute acid to remove carbonates, and after washing and drying, were analysed for carbon by combustion. The same carbonate-free samples were also analysed by the proposed method.

In Table 1 are shown the percentages of carbon determined by dry combustion and by chromic acid oxidation (assuming that 1 ml. of 0·2 N ferrous ammonium sulphate is equivalent to 0·6 mg. of carbon), together with the empirical factor which is their ratio. Its average value (1·15) is comparable with that found by ALLISON for soils under more drastic conditions. It may be seen that there is satisfactory agreement between replicate determinations. The variation of the factor is due in part to the error of the dry combustion method (standard deviation 0·03% of carbon). It is considered that the proposed method will determine organic carbon in muds with a coefficient variation of ca. 7% with 1% of carbon.

The same method may be used for the approximate analysis of plankton samples, in which case it is preferable to extend the heating period to $2\frac{1}{2}$ hours at 100°C. Under these conditions a correction factor of 1·05 should be employed.

Procedure

Reagents

Chromic acid. Dissolve 13 g. of chromium trioxide A.R. in a minimum amount of water. Add about 900 ml. of concentrated sulphuric acid and when cold, dilute to 1 l. with concentrated sulphuric acid.

Ferrous ammonium sulphate (0·2 N). Dissolve 39·3 g. of the reagent grade salt in 400 ml. of water containing 10 ml. of concentrated sulphuric acid. Dilute to 500 ml.

Ferrous-phenanthroline indicator. (0·025 M). Dissolve 0·337 g. of o-phenanthroline monohydrate in 25 ml. of 0·695% ferrous sulphate solution.

Preparation of samples

In order to remove salts, marine muds should be carefully washed with distilled water on a sintered glass funnel (Porosity 4), or on a Buchner funnel fitted with a fine-texture, hardened filter paper. After drying at 105°C. the sample should be ground to pass a 100-mesh sieve.

Method

Weigh out 0·3–0·15 g. of the prepared sample into a boiling tube (15× 2·5 cm.). Add 10 ml. of chromic acid from a wide-tipped pipette. Gently shake the tube and fit it with a loosely fitting bulb stopper. Heat in a bath of boiling water for 15 minutes. Cool, and pour the contents of the tube into 200 ml. of water. Add 1 drop of ferrous-phenanthroline indicator and titrate with 0·2 N ferrous ammonium sulphate solution until a pink colour just persists. Carry out a blank determination in the same manner but omitting the sample. 1 ml. of 0·2 N ferrous ammonium sulphate $\equiv$ 1·15× 0·6 mg. of carbon.

For the analysis of plankton samples, 10 mg. should be taken and the heating period extended to 2½ hrs. at 100°C. In this case 1 ml. of 0·2 N ferrous ammonium sulphate $\equiv$ 1·05×0·6 mg. of carbon.

Interferences

The most likely sources of interference in the proposed method are halide derived from sea water, ferrous minerals and ferrous salts. Coal and coke lost overboard from ships are sometimes found in mud samples from inshore waters and present possibilities or interference.

Since chlorides react with chromic acid in sulphuric acid with the formation of readily volatile chromyl chloride, their presence in the determination leads to high results for carbon. Thus, 0·15 g. of an organic carbon-free mud sample, to which 7·5 mg. of sodium chloride had been added, gave a titre equivalent to 0·41 mg. of carbon, i. e., to 0·27% of carbon in the mud sample. It is important therefore that before analysis the chloride content of muds should be reduced to less than 0·5% by washing with water.

In order to investigate the errors due to ferrous minerals, a chloritic schist containing 10·7% FeO and no organic carbon, which had been ground to pass a 100-mesh sieve, was examined. With 1 g. samples an average titre corresponding to 0·06±0·01% of carbon was found; the interference of ferrous minerals is therefore only slight. When the iron is present in a more soluble form, as in blue muds derived from a reducing environment, the error may be serious, in which case the soluble ferrous iron should be estimated and correction made for its presence.

The reactions of coal and coke were both tested for their reaction under the proposed conditions. It was found that 5–6 mg. of coal and 0·5 g. of

coke (both ground to pass 100-mesh) gave titres corresponding to 42% and 0·44% of carbon in the samples respectively. The interference of the amounts of coke likely to be found in marine muds is negligible, but the presence of coal will cause serious errors. Mud specimens which come from areas where coal is likely to be present should therefore be examined microscopically, and any coal found removed before analysis.

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Summary

A method is described for the analysis of marine muds for organic carbon, it is based on oxidation with chromic acid and titrimetric determination of the oxidant consumed. An empirical correction factor has been evaluated to correlate the carbon content found with that obtained by combustion. When ca. 1% of carbon is present, a coefficient of variation of about 7% is found. The method can also be used with slight modification for the approximate analysis of plankton.

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A Gauge for Determining Plankton Volume by the Mercury Immersion Method

By

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Introduction

In plankton studies involving regional or seasonal comparisons, the magnitude of the standing crop is frequently expressed in terms of volume. Numerous workers have shown that the conventional settling volumes are highly inaccurate, as trapped interstitial water tends to buoy some organisms up. Hence the most accepted volumes are those in which a major portion of the interstitial water is renewed. Displacement volume gauges have been described by EALEY (1954) and VSSACHEV (1939). Recently, FROLANDER (1954) introduced the use of a sintered-glass filtering apparatus for the determination of plankton volumes on samples obtained from Clarke-Bumpus hauls. Because the information obtained from plankton volumes is limited, it is necessary that determinations be done cheaply, easily, with reasonable accuracy, and without damage to the original sample. In our laboratory, the need for an apparatus which could be used over a wide range of plankton volumes has lead to the design reported here.

The writers acknowledge the technical assistance rendered by M. P. WENNEKENS and E. G. SCOTT, of the Department of Oceanography, University of Washington; and the Office of Naval Research, under Contracts Nos. N8onr-520/III, Project 083–012, and Nonr-477(10), Project NR 083–072.

The Mercury Immersion Method

Preserved plankton samples are poured directly into a glass receptacle fitted with a porous fritted-glass disk filter. The residual and interstitial water is removed by placing a rubber stopper connected to an air hose in the mouth of the receptacle. Air pressure is applied, which forces the water

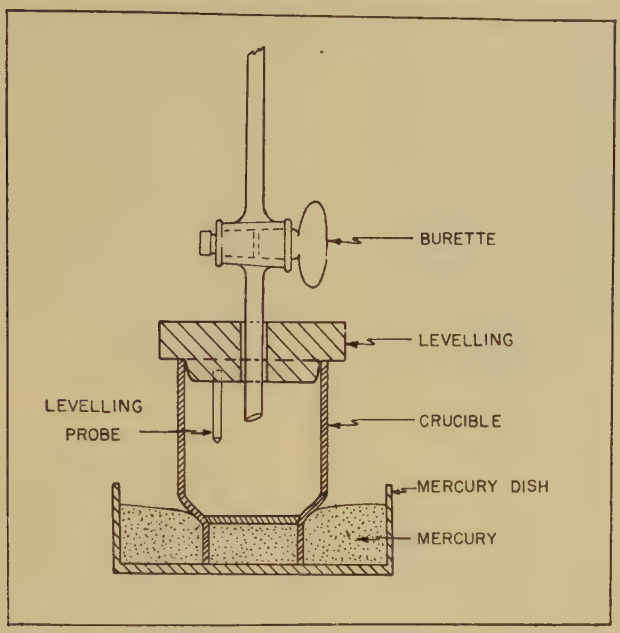

Figure 1. Component parts of the mercury immersion displacement volume gauge.

out through the porous disk. A brass cap supporting a pointed probe is fitted on top of the receptacle. The entire assembly (Fig. 1) is then placed in a dish of mercury in such a manner that the mercury surface is forced against the bottom of the sintered disk, thus sealing it. The tip end of a graduated burette is inserted through a hole in the levelling cap, and water is allowed to enter the receptacle from the burette. The water inflow is stopped when the water level reaches the tip of the probe. The difference in burette readings with and without plankton in the receptacle is termed the displacement volume. Two sizes of receptacle have been used, depending upon the volume to be determined (Fig. 2B). For plankton volumes from 0·1 to 10 cc., we recommend the "High Form" Gooch glass crucible, which has a disk diameter of 30 mm. and a total capacity of 50 ml. For larger amounts of plankton, the modified Buchner glass funnel with a 40 mm. disk diameter and a 150 ml. capacity serves adequately. The modifications include removal of the stem and flaring of the section below the disk into a circular rim. This is a simple job for an experienced glass-blower. Throughout the rest of this report the modified Buchner funnel is referred to as the large crucible. The pore size for Corning's coarse (C) sintered disk filter is given as 0·005 mm. As the finest plankton netting has a mesh-size of only 0·06 mm., the coarse disk will retain all organisms captured by standard netting procedures.

The levelling caps (Figs. 1 and 2B) serve to support the level probes. Our caps have been made from sections of brass rod, turned down on a

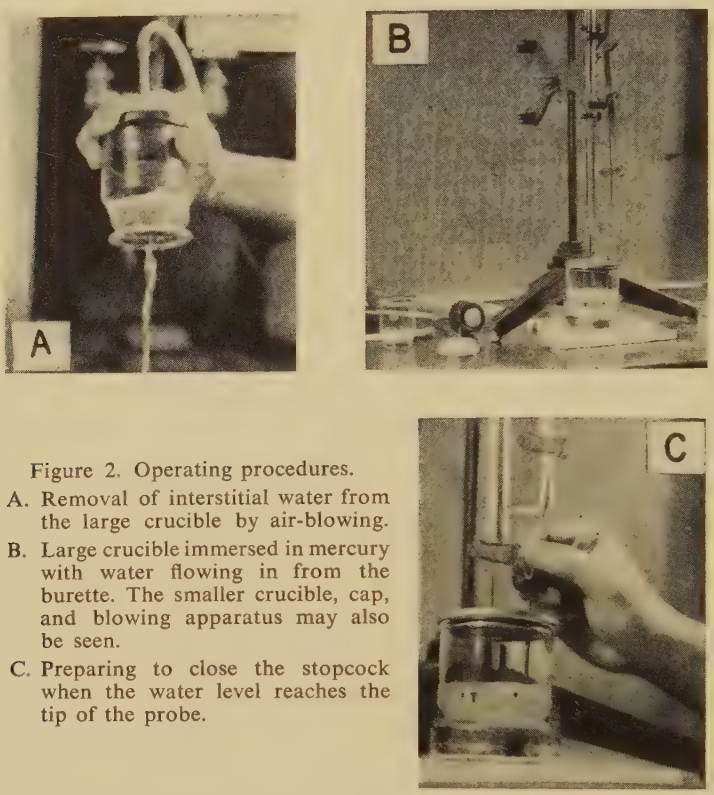

Figure 2. Operating procedures.
A. Removal of interstitial water from the large crucible by air-blowing.
B. Large crucible immersed in mercury with water flowing in from the burette. The smaller crucible, cap, and blowing apparatus may also be seen.
C. Preparing to close the stopcock when the water level reaches the tip of the probe.

lathe to fit loosely inside the mouth of the crucibles with a suitable portion overlapping the crucible rim. The total diameter for the "High Form" cap is 5 cm., which has an inside diameter of 4 cm. A hole 1 cm. across is made in the centre of the cap so that a burette tip may be inserted easily. The cap diameter for the large crucible is 7·5 cm. with an inside diameter of 6 cm. The centre hole for burette entry is 2 cm. across. Levelling probes for both caps are made of $^1/_8$-inch-diameter brass rod and are threaded into the caps approximately 1–2 cm. off the centre. The lengths of the probes may be varied according to the amount of plankton to be determined. For the large crucible the length most commonly used has been 2·5 cm., measured from the tip of the probe to the base of the cap. A 1·5 cm. length is used with the smaller "High Form" crucible. Probe points should be smooth, approaching a 45° angle on the sides of the point.

A 50 ml. Normax or Exax burette of the automatic filling type is used with the "High Form" crucible, whereas a 100 ml. burette may be used with the large crucible. A pyrex specimen dish (123×89 mm.) makes an excellent container for the mercury (Fig. 1). The bottoms of these dishes are slightly rounded, but may be levelled by placing several pieces of filter paper in the dish before introducing the mercury.

When the crucible is removed from the mercury, the breaking of the mercury seal will allow some water to pass through the filter disk on to the surface of the mercury. This water may be easily removed with a large basting pipette, followed by a gently patting of the surface with filter or other absorbent paper. Mercury dish, levelling cap, and crucible should be plainly marked to ensure exact positioning during successive trials.

Calibration

Exact calibration entails measurements of the volume of water that will fill the empty crucible to the tip of the probe. The fritted disk is wetted and the blowing stopper inserted (Fig. 2A). Air pressure should be applied until water vapour ceases to pass through the disk. This may be detected by wiping the inside of the crucible rim just below the fritted disk. The levelling cap is placed on the crucible, and the entire assembly is placed in mercury, sealing the fritted disk (Fig. 2B). The cap and crucible should be in the same position for each determination. This may be ensured by marking each piece with a reference line. The burette tip is inserted through the hole in the levelling cap to a position about 0·5 cm. above the tip of the levelling probe. The stopcock is opened and water is allowed to flow into the crucible until the surface makes contact with the tip of the probe (Fig. 2C). The burette reading in cubic centimetres is noted as the calibration number. After each determination the water is removed from the surface of the mercury with a basting pipette and filter paper. Several determinations should be made to confirm this number. The method of calibration is the same for either crucible size.

Procedure for running samples

Plankton samples are poured directly into the crucible, and the blowing stopper is inserted. Air pressure is applied until mist ceases to form on the crucible rim. The same procedure is followed as in calibration, with the difference in burette reading being expressed as plankton displacement volume. Frequently after initial removal of the residual water from the sample, re-suspension in the crucible is necessary to remove entrapped air.

Accuracy

Displacement volumes obtained by the Mercury Immersion Method were compared with volumes obtained by using a finely graduated centrifuge tube (10 ml.). Glass beads in numbers of 1 to 10 were first placed in the centrifuge tube and then transferred to a crucible and the displacement volumes compared (Table 1). The small deviations in these volumes result apparently from limitations in reading accuracy of graduations on the centrifuge tube. To obtain reproducible results the crucible and cap must be aligned similarly before each determination. The addition of 2 cc. of water in the "High Form" crucible changes the water level 3 mm., but only 0·3 mm. in the larger crucible; therefore it is apparent that any factor that alters the distance between the levelling cap and the probe tip produces a gross error. Care must be taken to ensure a smooth, continuous water inflow from the burette;

Table 1

Displacement volumes determined by a graduated centrifuge tube and the mercury immersion method

Crucible type	Glass bead numbers	Displacement volume by centrifuge tube (cc.)	Displacement volume by Mercury Immersion Method (cc.) I	II
Large	10	1·33	1·34	1·35
	5	0·70	0·73	0·73
	1	0·25	0·30	0·30
"High Form"	10	1·23	1·21	1·24
	5	0·67	0·71	0·73
	1	0·20	0·19	0·21

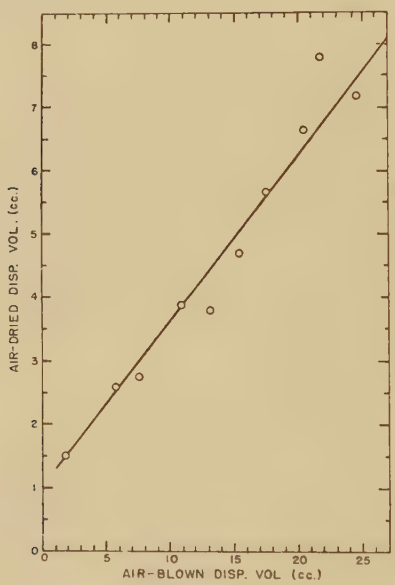

Figure 3. Relationship between plankton volumes from which the interstitial water was removed by air-drying for 24 hours, as compared with water removal by blowing air through the sample.

Table 2

Percentage of water removed (total porosity) by three techniques of water removal

Settlement Volume Vs	Volume by Ratio[1])	Volume by Merc. Immer.	Air-blown % Por.	Filter % Por.	Air-dried % Por.
41	10·25	6·04	85	75	94
75	17·75	10·90	76	76	97
106	26·25	24·51	85	74	93

[1]) The ratio of settlement to displacement volume is given by FLEMING (1940) as 4·1. Our studies indicate that this ratio is highly variable, averaging 8·0 for 100 samples.

surface ripples arising from disrupted flow will cause a premature contact between the water level and the probe tip. The reaction time for closing the burette stopcock when the water level makes contact with the probe varies with the individual. These variations are probably not important, as the delivery times for the 50 ml. and 100 ml. burettes are 0·4 and 0·7 cc./sec., respectively, and reaction times are of the order of 1/100 of a second. If the same operator runs a series of samples, the reaction times for calibration and sample running should be constant.

Interstitial Porosities of Mixed Zooplankton Samples

The probability of obtaining the true displacement volume depends upon the complete removal of all interstitial water. Table 2 lists the porosities, or percentage volume of water removed by three methods. Total porosity is defined as $\frac{Vs-Vd}{Vs}$ (100), where Vs is the settlement bulk volume and Vd is the displacement volume. With FLEMING's (1940) ratio between settlement and displacement volumes, obtained by a filtration technique, a porosity average of 75% is obtained. Water removal by the air-blowing process reported here gives average porosities of 85%. Samples air-dried for 24 hours yield porosities as high as 97%.

Prolonged air-drying, in contrast to the air-blowing process, removes interstitial water that is tightly bound in some manner within the sample. The efficiency with which the air-blowing process removes interstitial water depends upon the area of surface exposed to the process, as compared to the total volume of the sample. The amount of interstitial water removed by air-blowing as compared to air-drying (24 hrs) for specific plankton volumes is shown in Figure 3. With plankton volumes of 1 cc. or less, the blowing process removes most of the interstitial water; as the volume of the sample increases, the amount of interstitial water retained increases markedly.

It is apparent therefore that with large plankton volumes, particular care must be taken to ensure removal of the greater portion of the interstitial water. Re-arrangement of the packed sample during the air-blowing process or splitting the sample into component parts are the suggested alternatives.

Summary

A plankton volume gauge is described by which the displacement volume of preserved plankton samples may be conveniently and accurately determined. A glass receptacle, fitted with a porous filter, holds the sample while the interstitial water is removed by stoppering the receptacle and forcing air inside. A constant water volume is established within the receptacle by sealing the filter in mercury and filling to a level indicated by contact with a probe. The difference in the volume of water needed to fill the empty receptacle in contrast to the receptacle with plankton is the sample volume.

Volumes are measured with either 50 or 100 ml. burettes. Reproducible results are easily obtained, and the degree of accuracy is high.

The amount of interstitial water remaining after the air-blowing process depends on the sample size. For this reason, when large plankton samples are dealt with, in which the surface area exposed to the water removal process is small in contrast to the total sample volume, extreme care should be used to ensure complete removal of the interstitial water prior to the volume determination.

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On the Transport of Live Cod and Coalfish

By

Gunnar Sundnes

Introduction

Though the practice of transporting live cod (*Gadus callarias* L.) and coalfish (*Gadus virens* L.) in well-boats has been carried on for a long time in Norway, many of the problems connected with the load the well can carry and the occurrence of mortality among the fish are still unsolved. The solution of such problems, for any species of fish, is of fundamental importance in the planning of fish transplantation and some knowledge of the energy metabolism or oxygen consumption of the two species mentioned above may therefore be of value.

The energy metabolism has been studied for many species of fishes; LEINER (1938) and BLACH (1951) have reviewed the literature on the subject, for example. No work seems to have been done, however, on the oxygen consumption of cod and coalfish after the larval stage.

The Problem

The main problem is to supply enough oxygen to meet the demand made by the fish. Lack of oxygen is the most rapid and effectively lethal agent during the storage and transport of live fish. Examination of other factors in the external environment of the fish is not so important because all systems of storage and transport in use in Norway today are varieties of the "circulation system", involving communication with the sea. Within the transportation area, variations in the physical and chemical properties of the sea water (Fig. 1) are small.

The system used in Norwegian well-boats is shown schematically in Figure 2. The water exchange in the well is greatest when the ship is travelling at full speed. When the ships are being loaded and unloaded a vigorous water pump is used, but the circulation provided by the pump is less than that produced by the passage of the ship through the water. The following facts have been learnt from experience: —

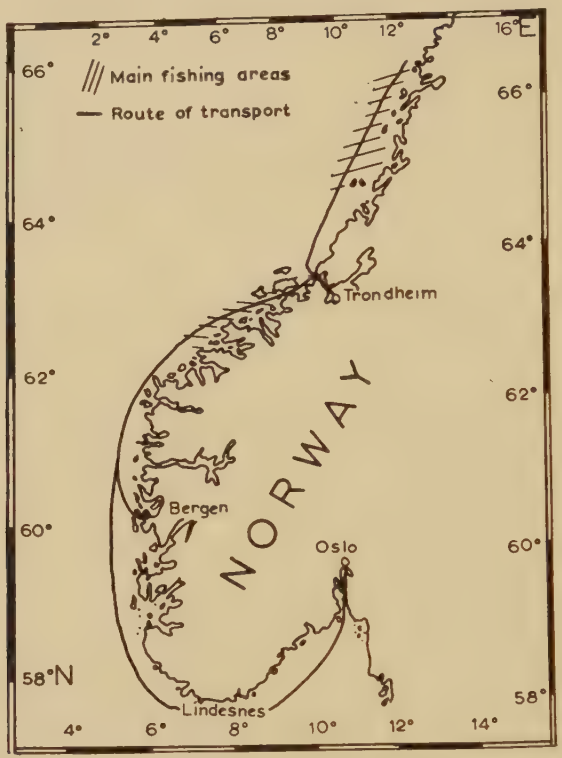

Figure 1. The route followed by well-boats in transporting fish. As the surface salinity between Lindesnes and Oslo is sometimes low, the well may be closed over this part of the route.

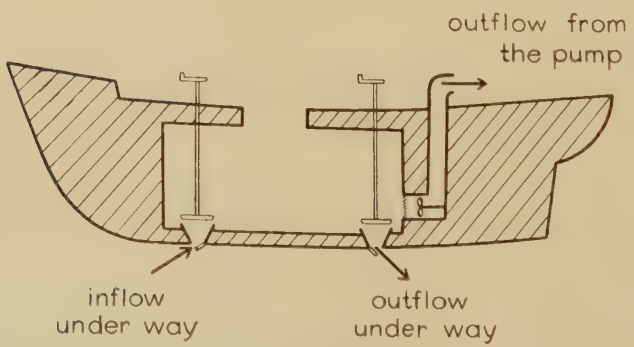

Figure 2. The system of water circulation used in Norwegian well-boats.

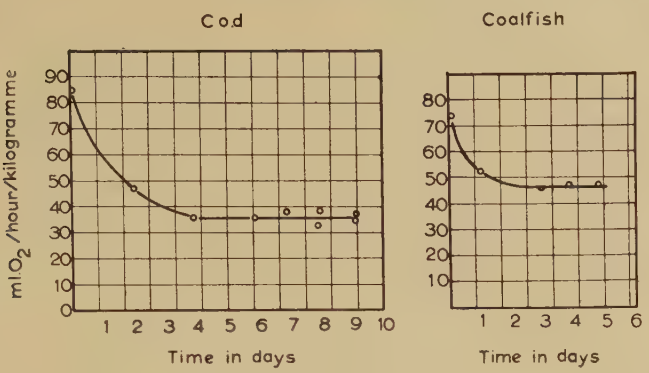

Figure 3. The oxygen consumption of a cod of 1750 g. and a coalfish of 1020 g.

After the well has been loaded with cod or coalfish, the ship must proceed at full speed immediately, because the capacity of the pump is too small to provide for the oxygen requirements of the fish. However, after a day or two at sea, when the fish have settled down, the pump alone is able to keep the fish alive, even when the ship is stopped.

Under identical conditions, all well-boats can keep more cod alive than coalfish.

As lack of oxygen seemed to be the most common lethal agent, an investigation of the problem of oxygen consumption was started. The effects of factors such as salinity and temperature were also studied, but they are not discussed in the present paper.

Experimental

The quantities of oxygen consumed by cod and coalfish were measured by chemical analysis of the water in gas-tight aquaria. WINKLER's method, with KROGH's (1934) modification, was used in determining the amount of dissolved oxygen. The results of the investigation showed that the fish consumed large quantities of oxygen just after they had been put into the experimental aquarium. Later on, the rate of oxygen consumption decreased till it reached a constant level. Similar results were obtained previously for other species by KEYS (1930), and HAUGAARD and IRVING (1943). Both cod and coalfish showed significant increases in oxygen consumption immediately after being transferred to the experimental aquarium (Fig. 3), the metabolic rate being about twice the normal rate. No difference was found between the quantities of oxygen normally consumed by cod and coalfish.

Measurements were also made of the energy metabolism of fish in samples of sea water which varied in oxygen content. The results show a significant difference between cod and coalfish with regard to the critical quantities of dissolved oxygen (Fig. 4). The critical quantities for cod and coalfish are about 2·7 ml./l. and 1·8 ml./l. respectively. With the coalfish the critical

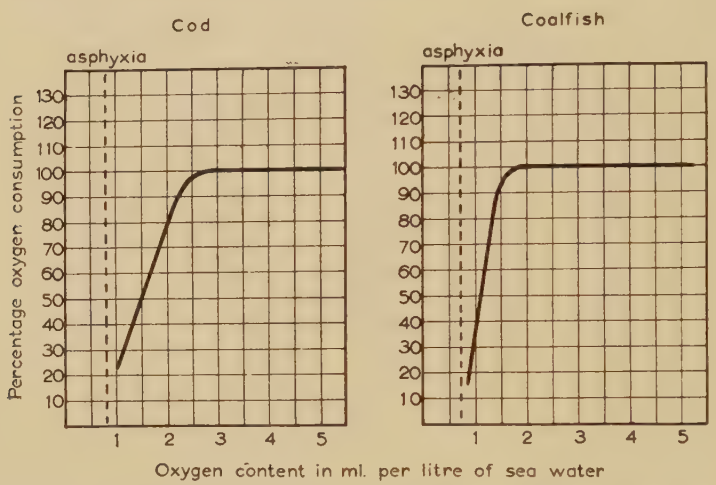

Figure 4. The oxygen consumed by cod and coalfish for different amounts of oxygen dissolved in the water, stated as a percentage of the normal metabolic rate.

quantity of oxygen is nearer the quantity at which asphyxiation occurs than with the cod, asphyxia being defined here as loss of balance by the fish. Cod are asphyxiated when the oxygen content falls below 0·80 ml./l., and coalfish when it is below 0·73 ml./l. As no blood analyses were made, the results are not exact enough to be considered as true physiological values, but they are satisfactory for practical purposes. The water temperature was kept within the limits of 8·7 and 10·7°C. during the experiments.

The experiments were always made with healthy fish; pathological conditions merely complicate the picture. Wounds in the skin, accompanied by lethal infections, are quite common among coalfish. Such wounds are acquired while the fish are being handled and during storage.

Experimental Results in the Light of Practical Experience

The results of the experiments explain some of the practices adopted as a result of experience. The necessity for the well-boat to travel at full speed as soon as the fish are on board is explained by the increase in the fish's metabolic rate after transference to the well, as occurred in the experimental aquarium. Accordingly the capacity of the well is determined by the quantity of fish that can be kept alive just after loading. The difficulty is to satisfy the enormous demand for oxygen at this stage. When the fish have become accustomed to the well and metabolism has fallen to normal, the capacity of the well in these circumstances is not fully employed. This has been confirmed by observations in fully loaded well-boats after they have been at sea for one or two days. The oxygen content of the water in the well was then nearly the same as that of the sea outside.

When a well-boat has been loaded with live fish to its maximum capacity,

the oxygen content of the water decreases till equilibrium is reached between supply and consumption. After some time, when the metabolism of the fish is proceeding more slowly, the quantity of oxygen in the water in the well increases. Such a train of events has already been observed in other experiments (SUNDNES, 1953). In the well-boat, therefore, the flow of water may be reduced after some time under way. Supply and consumption of oxygen must reach equilibrium at about the point at which asphyxiation of the fish occurs. The well is then loaded to its maximum capacity.

The difference between the numbers of cod and coalfish which can be loaded into a particular well-boat does not depend on the existence of a difference between the asphyxiation levels of the two species. If the level of asphyxiation were the factor deciding loading capacity, the well-boat ought to be able to take more coalfish than cod; but this is not the case. Let us assume that the fish in the well stabilize the oxygen in the water at about 2 ml./l. just after loading. From the curves in Figure 4 we can see that in water of this oxygen content the coalfish has a normal metabolic rate, but for the cod the metabolic rate is 20% below the normal level. Experiments have shown, however, that cod can live for several hours at this metabolic rate, and accordingly the well must be loaded with more cod than coalfish in order to stabilize the quantity of oxygen in the water at 2 ml./l. The observations are too few to give the exact relation between the numbers of cod and coalfish which can be put into the well.

To load the well with coalfish to a point at which the quantity of oxygen in the water is sufficient to maintain a metabolic rate of 80% of the normal for the coalfish is not possible in practice. This would demand an exact stabilization of the oxygen content very near the point at which asphyxiation occurs.

The assumption that it is preferable for the oxygen content of the water to be stabilized at 2 ml./l. has been proved by observations made on board the well-boat "Levendefisk 1". The water in the well of this vessel had an oxygen content of 2·1 ml./l. just after loading. It is presumed that the different loading capacities for cod and coalfish arise from the difference between the quantities of oxygen which are critical for the two species.

Summary

The present investigation shows that the number of live fish which a well-boat can carry depends upon the oxygen supply and the rate of oxygen consumption just after the well has been fully loaded. After some time under way the capacity of the well is not fully employed. The numbers of cod and coalfish which can be put into the well depend upon the different quantities of dissolved oxygen which are critical for the two species.

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The Culture of Oysters in North-Western Spain

By

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The most characteristic feature of the rivers of Galicia (N.W. Spain) is the "ria", the long inlet by which the sea enters the submerged valley of the river. In what we call the "low rias", particularly those of Arosa and Vigo, some basins exist which provide magnificent conditions for the cultivation of oysters; in both places various projects have been undertaken for oyster culture on an industrial scale.

Work was begun in 1935 on the grounds in the basin of San Simon, at the head of the Vigo "ria", and connected with it by the Straits of Rande. Two rivers and numerous rivulets flow into the basin, in which the salinity of the water and the plankton are very favourable for the development of the flat oyster (*Ostrea edulis*).

The floor of the basin consists of a mixture of sand and clay of moderately solid texture. The salinity of the water is between 23 and 29 $^{0}/_{00}$, and since the oyster spawns at water temperatures between 15° and 18°C., when the temperature exceeds 15° free larvae can be found; they are most numerous at temperatures from 18° to 22°C. The pH of the water in the San Simon basin oscillates about 8·1, according to investigations made by the Oceanographical Laboratory at Vigo.

The majority of the larvae settle in the lower layers of water, which suggests that the natural habitat of the larger larvae is in that zone.

During the year 1935 we made the first tests with limed tiles, and collected large numbers of oyster spat, about 200 on every tile. The tiles were coated with a mixture of equal parts of lime and sand so that a covering 2 mm. thick was formed.

In the Galician "rias" the flat oyster begins to spawn in early May. Spawning is intense and the larvae may set in large numbers, if the temperature and salinity are favourable; the production of larvae continues until October, so that considerable quantities of spat can be collected, if care is taken to keep the collectors clean.

Our tests were confirmed by NAVAZ in 1939, who used the same collectors, and set them out in the same part of the "ria".

In 1942, the firm of Viveros del Rial, of Villagarcia, set out, under our direction, 100 collectors containing limed tiles and collected about 2,000,000 young oysters, this being the first occasion on which attempts at oyster culture on a commercial scale had been made in Spain.

We do not assemble the collectors where they are to be set up, as the French do, but prepare them on shore. They are then loaded on to a barge, and deposited by means of a set of sheer-legs on the chosen site. The collectors are made up in a wooden frame, which is as long as four tiles and as wide as one. Five rows of tiles are arranged one on another, the tiles being placed lengthwise in the frame alternately with others placed across it. The frame is fited with handles, for convenience of transport, and it also has legs about 20 cm. long, to hold the frame off the ground, and keep it clean.

During the tests described, collectors were placed on the left-hand side of the basin, off Monte Gordo, in such a position that they were uncovered at low water, spring tides.

The operation referred to above met with great success, and the limed tiles appeared to be quite covered with spat. For this reason the young oysters were removed from the tiles when the majority were still very small, about 7 mm. (SANCHEZ y SANCHEZ, 1944). The end of summer is a very convenient period for removing the young oysters from the tiles, a process that can be easily accomplished without damage to the oysters.

To hold the oysters while they are growing we use specially designed cages. These are rectangular in shape and are about 60 cm. long, 40 cm. wide, and 4 cm. high. The novel feature of these cages is that the long sides are made of galvanized wire netting so that the water can circulate freely through them. This arrangement has given very good results. The lid and bottom are of wood, and fit closely to the sides through which the water flows. To prevent the oysters from being washed out of the cages by the current of water, the sides are solid for about 1 cm. above the floor of the cage.

The cages containing the young oysters are set out in a single layer on supporters which hold them about 20 cm. above the ground, on the edge of the channel, in such a way that they can be seen at spring tides. The shore at Cesantes is an ideal place for the growth of young oysters.

When the oysters are larger, they are transferred to cages built in the same way, but which are four times as long.

The rate at which the oysters grow in these cages is extraordinary; at 9 months they reach a size of about 6 or 7 cm; if these oysters are laid on the ordinary beds they attain a size of 9 cm. when they are 16 months old.

The oysters continue to grow throughout the whole year, the amount of growth depending on the quantity of plankton available, which is in turn related to the quantities of nitrate, phosphate, and organic material present in the basin.

ANDREU and ARTÉ (1955) have recently carried out experiments on the setting of oysters in San Simon basin, but they obtained only very moderate

results, which they atrribute to the decline of the oyster beds. Those authors also studied the growth of the oysters during winter, and have confirmed the finding that growth is rapid.

We have installed collectors of the type described above in the Rianjo basin (Arosa "ria"), in which the biological conditions resemble those at San Simon, and have found that the larvae set in the same quantities as were observed at San Simon.

Summary

An account is given of the progress that has been made in the development of oyster culture on a commercial scale in some of the "low rias" at the mouths of the rivers of Galicia, where the conditions are exceedingly favourable. Initial trial with limed tiles having proved successful, the first attempts at culture on a commercial scale were made in 1942. One hundred wooden frames carrying the limed tiles were set up as collectors and from them about 2,000,000 young oysters were obtained.

The young oysters are usually removed from the tiles towards the end of summer, and grown on in specially designed cages. Growth is rapid and continues throughout the year.

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Factors Affecting the Pollution and Self-Purification of Molluscan Shellfish

By

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Introduction

In England and Wales little attention has been directed towards the seasonal variations of pollution which occur in oysters, although this aspect of shellfish pollution has been studied by workers in the North Atlantic States of America and Canada. SMITH (1912) reported the coliform content of oysters taken from Narragansett Bay to be considerably lower in winter than in the summer, although there was no corresponding change in the number of coliforms in the sea water. Other workers reported similar findings (GORMAN, 1912; CUMMING, 1916; GAGE and GORMAN, 1925; GIBBARD *et al.*, 1942) and nowadays legislation in certain areas of the North Atlantic seaboard allows for the sale in winter of oysters from grounds which produce grossly polluted oysters in the warmer months (NEEDLER, 1951; HOMANS, 1955).

Few previous observations are available for England and Wales. In the 1930's during an investigation at the Conway Laboratory of the Ministry of Agriculture, Fisheries, and Food of methods for the cleansing of oysters under conditions of low water temperature, it was noted that oysters taken in winter from grounds which produced highly polluted mussels were virtually unpolluted. The significance of this was not appreciated at the time and oysters for experiment were later placed either in tanks of diluted sewage or directly beneath a sewage outfall. Such oysters could not fail to become highly polluted, since the residual water within the mantle cavity alone would contain sufficient bacteria to give small samples of the tissue the appearance of gross contamination.

More recently, COLE (1954), from a limited series of observations, noted that oysters from a polluted ground in the river Crouch contained few

bacteria of faecal origin during winter, whereas large numbers were present in the warmer spring and summer months. He pointed out that temperature mainly affected the rate of filtration of oysters, and did not consider that the observed variation of pollution was associated with seasonal changes in the amount of sewage entering the river, since the period of maximum population, viz., August and September, did not coincide with the period of maximum pollution of oysters. No observations were made of the incidence of *Bact. coli* in waters over the grounds during these experiments, although VACCARO *et al.* (1950) showed that these organisms remain viable in sea water for a longer period in winter than in summer.

It was thought desirable to obtain more data and to extend the observations to include the mussel (*Mytilus edulis*). A preliminary investigation into the seasonal variation of pollution was therefore started in 1954 and samples of native oysters (*Ostrea edulis*), mussels, and water were collected simultaneously from a fixed sampling point on the Southward Laying, river Crouch, at weekly intervals.

The samples were examined bacteriologically for the presence of faecal *Bact. coli* by methods described later and it appeared that a rise in water temperature was associated with an increase in the counts of faecal *Bact. coli* per ml. of oyster tissue. Although observations with mussels were not made when water temperatures were extremely low, a similar, although less obvious, correlation was evident. Water counts showed wide fluctuations, which did not appear to be correlated with the levels of pollution attained by the shellfish. At this stage of the experiments, water and shellfish samples were collected at or near low water, but no attempt was made to collect them precisely at the observed time of slack water at low tides. It was thought probable that the variations observed in water pollution were the result of tidal movements which altered the bacterial quality of the water passing over the grounds.

It is established that polluted molluscan shellfish cleanse themselves when placed in tanks of clean water but little is known of the processes of pollution and cleansing of those shellfish which occur under natural conditions in situations where the level of pollution of the water varies within the tidal cycle. These variations were therefore studied, and this led to a comparison of the processes in oysters and mussels during winter and summer months.

Methods

The Southward Laying of the river Crouch, the ground selected for these experiments, is situated within the closed area prescribed in the Public Health (Shellfish) Regulations (1934) and is approximately half a mile downstream of the main sewage outfall of Burnham (population approximately 4,000 with seasonal increases). This outfall discharges virtually raw sewage through a tidal valve for a period of approximately 2 hours on each side of low water. Downstream from the oyster ground there are no polluted outfalls, and since the river is tidal, the oyster ground is subject to the flow of highly polluted water on the ebb, and of virtually clean sea water

on the flood, a set of conditions which is by no means uncommon in estuaries where cultivation is practised.

Bacteriologically clean oysters and mussels were placed in a weighted and buoyed cage at a point on the shore just below low water of spring tides. To eliminate any interference in the functioning rate which might result from the disturbance of the cage at hourly intervals during the collection of samples, several smaller cages, each holding one sample, were later substituted for the single cage.

Oysters were selected for evenness of size and were normally 3 to 4 years old. In later experiments some attempt was made to use only oysters showing indications of rapid growth (broad, thin bands of newly deposited shell) on the assumption that these were of similar filtering capacity, but no significant differences were noted as a result of this refinement. The mussels were 2 to 3 years old, and were selected for evenness of size and smoothness of shell.

Sufficient shellfish for each experiment were placed in the cages and left for at least 24 hours before the commencement of sampling, in order that they might assume the bacterial characteristics of the ground. Samples of 4 oysters and 4 mussels were then collected at approximately hourly intervals throughout the day, each sample being placed in a separate sterile tin. At the same time, water samples were collected from the bottom of the river near the sampling point.

All samples were examined bacteriologically within a few hours of collection, by means of a modification (Reynolds and Wood, 1956) of the roll-tube method of Clegg and Sherwood (1947). Shellfish tissue from each sample was pooled, extracts prepared, and four tubes containing 5 ml. of modified MacConkey agar each inoculated with 1 ml. of extract. The bacterial content of the water was determined from 2 ml. of water in each of 5 tubes holding 5 ml. of MacConkey agar (Wood, 1956). After rolling, the tubes were incubated overnight at 44°C. in an accurately controlled water-bath. The red colonies representing faecal *Bact. coli* were counted and the results finally expressed as the number of faecal *coli* in 1 ml. of tissue or 10 ml. of water.

Results and Discussion

From topographical evidence, wide variations would be expected in the bacterial quality of the water passing over the sampling point, and this was confirmed by these tests. During each experiment, there appeared to be a well-defined cycle of pollution characterized by high counts of faecal *Bact. coli* around low water, and low counts during the flow of water from the sea and on the first of the ebb before the sewer started to discharge (see Figs. 1, 2, and 3, which are representative of a larger series of similar results). This pattern was evident in all except one of the many experiments done (foot of Fig. 1), but the levels of pollution in each cycle differed considerably. This was probably the result of the influence of a number of varying factors, but the volume of sewage discharged and the strength and direction of the wind appeared to be the most important.

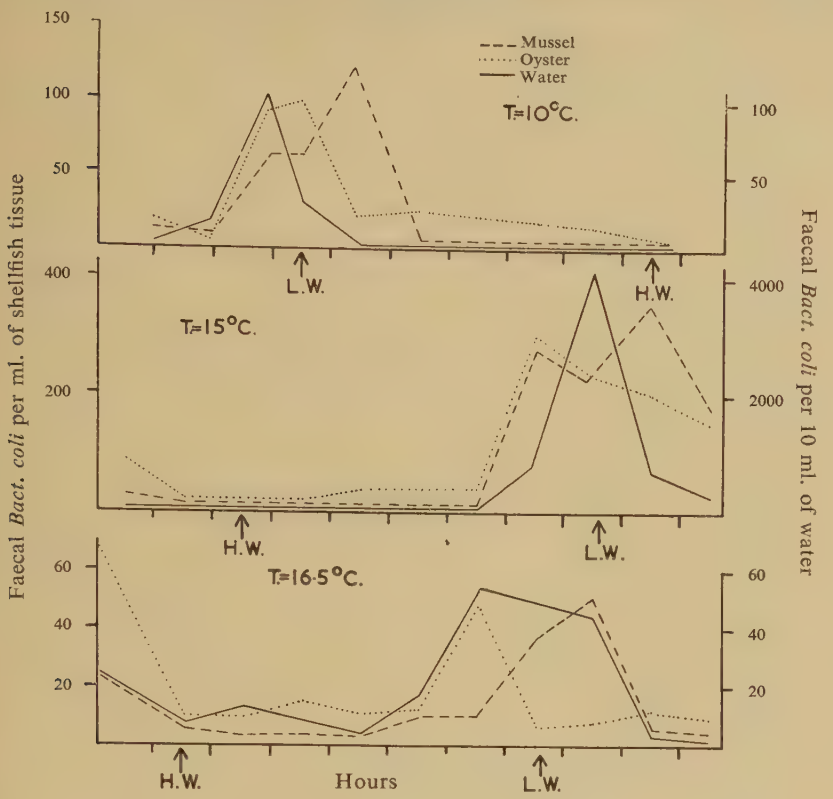

Figure 1. Tidal cycle of pollution and cleansing of oysters and mussels when water temperatures were above 10°C. The correlation between the bacterial content of water and shellfish is shown. Where very low counts coincide with one another or with the abscissa, they have been separated, to avoid confusion; counts in this region are therefore lower than those illustrated. L.W. = low water; H.W. = high water; T. = temperature of water.

In most of the summer experiments there was a close correlation between the bacterial content of the water and of shellfish, but as experiments continued through the winter, it appeared that the characteristic pattern of pollution of the oyster in winter differed from that observed in summer. In some experiments the expected changes in the level of pollution did not take place. It is therefore convenient to divide the results into three groups.

(a) Pollution in summer (Fig. 1)

When water temperatures were between 10° and 16·5°C. there was a close association between the bacterial content of the water and the shellfish. Both oysters and mussels became grossly polluted in the period around low water when the water showed its maximum count, but they quickly

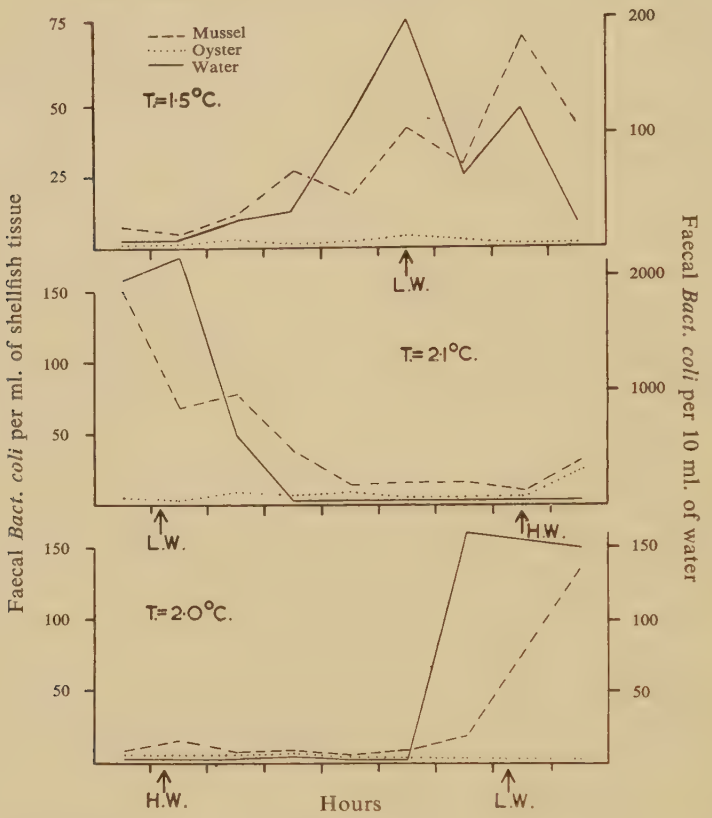

Figure 2. Tidal cycle of pollution and cleansing of oysters and mussels when water temperatures were between 1·5° and 2·1°C. The lack of correlation between the bacterial content of water and oysters is shown. For further details, see Figure 1.

cleansed themselves with the flow of bacteriologically clean water from the sea. In the first experiment, mussels cleansed themselves within one hour of maximum pollution, and oysters did so after six hours. At these temperatures, the oyster and mussel are known to filter at a rapid rate, and it is understandable that bacteria were quickly removed from their alimentary tracts with the flood of clean sea water. It is noteworthy that these experiments were conducted during periods of calm winds; the significance of this will be discussed later.

(b) Pollution in winter (Fig. 2)

The second group of experiments, also done in calm weather, but when water temperatures were between 1·5° and 2·1°C., showed that the pattern of pollution of the oysters was different from that in summer. Mussels continued to function at what appeared to be a normal rate, becoming polluted and then clean in a manner similar to that occurring during

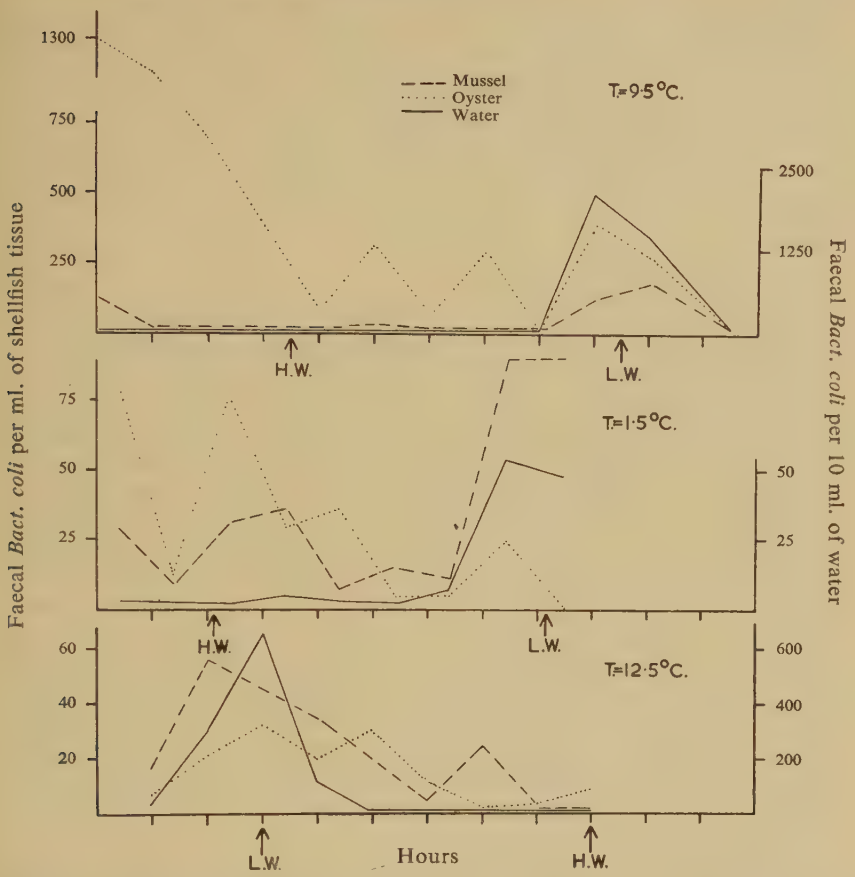

Figure 3. Tidal cycle of pollution and cleansing of oysters and mussels when water temperatures were between 1·5° and 12·5°C. The lack of correlation between bacterial content of water and shellfish is shown. For details, see Figure 1.

summer, whereas oysters remained virtually unpolluted, even when mussels and water became grossly polluted at low water. Mention has already been made of the works of GORMAN (1912), CUMMING (1916), GAGE and GORMAN (1925), and GIBBARD *et al.* (1942), who observed similar conditions on the coasts of the North Atlantic. PARSONS (HUNTER and HARRISON, 1928) described seasonal variations in the level of pollution of oysters, and demonstrated that pollution became very low when the water temperature fell to 3·5–5·5°C. Experimentally, GALTSOFF (1928) and LOOSANOFF (1950) were unable to detect water propulsion in the American oyster at temperatures below 5°C. The filtration rate in the mussel is not affected by the reduced temperature to the same degree (GRAY, 1928), and active filtration continues in the mussel at temperatures down to 0°C. (DODGSON, 1928); this has been confirmed during many years of mussel cleansing at Conway.

There is little information about the mechanism by which oysters in polluted waters remain but lightly polluted at low temperatures. Needler (1941) has suggested that the reduced filtration rate is accompanied by a slower rate of passage of food through the gut, during which time viable bacteria are subjected to the bactericidal substances of the digestive juices for a longer period. Unpublished work done by H. M. Webb at Conway indicated the presence of a thermolabile bactericidal substance in oyster tissue.

(c) Abnormal pollution (Fig. 3)

Both the previous groups of experiments were made during periods when there was little wind. In the third series of experiments, done under more turbulent conditions at varying temperatures, the expected correlation between the levels of pollution of water and shellfish did not appear. Successive samples frequently showed wide deviations from one another, this being more evident for oysters than mussels. It was clear that some other factor was interfering with the "normal" pattern of pollution, and although the matter has not yet been extensively examined, observations of the weather showed that this irregularity occurred during periods when onshore winds caused heavy turbulence. The experimental cages used in these experiments were situated at the level of low water, springs, and for a large part of these experiments were in relatively shallow water where turbidity would, in these circumstances, be excessive. It is highly probable that the filtration rate was modified by the presence of suspended silt. The influence of turbidity has been examined experimentally by Kellogg (1915), Loosanoff and Engle (1947), and Loosanoff and Tommers (1948). The last-named workers demonstrated that the filtration rate of the American oyster (*Crassostrea virginica*) was reduced by as much as 80% in the presence of relatively small quantities of silt.

The possibility of other factors causing these discrepancies cannot be ignored. Salinity and oxygen tension probably varied but little in these experiments, as sea water flowed in and out of the estuary at a rapid rate and there was little fresh water entering the river. Other workers have examined shellfish to see if there is an association between the filtration rate and tidal movements. Loosanoff and Nomejko (1946) failed to detect a tidal or diurnal periodicity in the filtration rate of the American oyster, but Rao (1954) recorded pronounced tidal rhythms in *Mytilus edulis* and the Californian mussel (*Mytilus californianus*), which showed maximum filtration rates at the time of high water. It is possible that such a cycle was in operation during these experiments, but it is highly unlikely that it would lead to the discrepancies observed here.

Significance of these Experiments in Relation to Public Health

The experiments described above indicate the dynamic nature of the pollution and cleansing of shellfish from grounds which are subject to intermittent pollution. A single sample can give but little information about

the sanitary quality of a shellfish ground, and as previous workers have indicated (Dodgson, 1928; Knott, 1951), a representative series of samples must be collected under varying conditions of wind and tide.

On oyster beds, investigations in summer normally show the maximum level of pollution to which the shellfish are subjected, but do not provide a reliable guide to winter conditions.

Dodgson (1928) recommended the mussel as a more reliable indicator of pollution than the oyster, and frequently used mussels to determine the level of pollution of an oyster bed. In view of the physiological differences between these two shellfish, this is to be deprecated, since under certain conditions pollution of the oyster is light, whereas that of the mussel is heavy.

Before the seasonal variation in pollution of oysters can be put to economic advantage, further work is required. Firstly, the effect of suspended silt upon natural purification must be more closely examined, and secondly, the upper limit of water temperature at which oysters laid on polluted grounds fail to become significantly polluted must be determined. With these questions answered, it might be possible in winter to utilize oysters from certain grounds exposed to contamination; the fact that active filtration continues at normal winter temperatures precludes this possibility for the mussel.

Summary

A description is given of the natural processes of pollution and cleansing in oysters (*Ostrea edulis*) and mussels (*Mytilus edulis*) in an estuary subject to intermittent pollution.

When water temperatures are above 10°C., pollution and cleansing take place rapidly as the quality of the water overlying a shellfish bed alters, and both types of shellfish may become highly polluted at these temperatures. When water temperatures are in the region of 1–2°C. mussels continue to show the same pattern of pollution and cleansing, but oysters may not become polluted, even when the water overlying them contains large numbers of faecal bacteria.

During rough periods, the cycle of pollution and cleansing was not in evidence. It is suggested that this might be the result of an interference in the normal functioning processes by excessive turbidity. It is hoped that with a greater understanding of these factors, it might be possible, when water temperatures are low enough, to market oysters from polluted waters.

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Reviews

H. W. Harvey. "The Chemistry and Fertility of Sea Waters". 224 pp., 65 figs. Cambridge & London, University Press, 1955.

As the population of the world grows, so does the need to exploit to the full the food resources of the sea. The search for fresh fishing grounds and the development of the technique of fishing are therefore fundamental tasks for the marine fishery scientist. To put this programme into practice the United Nations have set up the Food and Agriculture Organization. This international body has the benefit of the knowledge acquired, for example, by the International Council for the Exploration of the Sea, through which most of the countries of Europe from Spain to Scandinavia have been able to work together and share their knowledge for more than half a century. The need of the underdeveloped countries for immediate assistance, however, tended to confine FAO's activities at first to technical matters, but future extension of their work must be the promotion of fundamental research on a world-wide scale.

The productivity of the oceans can become useful to mankind only when the facts being accumulated in different parts of the world about the conditions that govern life in the sea have been assembled and can be studied and assessed by a staff of workers devoted to a high ideal such as that upon which FAO is founded. For this reason we should be grateful to Dr. HARVEY for compiling the latest information on the fertility of the sea, a subject which is indeed one of the principal aspects of oceanography. HARVEY surveys the oceans as a whole; their chemistry, physics, and biology are brought together and focused on the concept of fertility. His new book is virtually a third edition of *Biological Chemistry and Physics of Sea Water*, which first appeared in 1928. The change in title and, to some extent, contents is the result of the great advances in knowledge made in recent years. The enormous progress in biochemistry especially has necessitated a fresh arrangement of the chapters.

The book is divided into two parts, the first of which begins with a general survey of the composition of sea water, with special reference to the carbonate system, and goes on to describe the various agents by which the substances composing sea water are transported and distributed. The

causes of vertical mixing — the stirring effect of the wind, for instance, and the topography of the sea floor — are shortly discussed. The importance of the restrictive effect of the thermocline on mixing is stressed. The horizontal distribution of the water masses brought about by currents is described as it occurs in shallow water and also in the open sea.

The most fascinating chapter in this part of the book is that which deals with the changes in the composition due to plants and animals. The cycles of the principal elements controlling life — phosphorus, nitrogen, carbon, and oxygen — are described. Bacteria are largely responsible for changes taking place in the ocean. They dominate the nitrogen cycle and play a part in the carbon-oxygen and the phosphorus cycles. Many of the oxidation processes in sea water are due to the activity of bacteria; not only are they able to break down organic matter, either in solution or particulate, and excrete it as re-mineralized products, but they also produce enzymes which act as catalysts in oxidization processes. Moreover, as well as giving rise to reduction processes, they are assumed to excrete growth-promoting substances. Their rapid metabolism and their extended distribution, with population maxima in the surface layers and on the sea floor, makes them a very important factor in the biochemistry of sea water.

The following chapter deals with factors influencing the growth of plants, such as illumination, supply of nutrient salts, temperature, turbulence, and the herbivorous zooplankton. Numerous laboratory experiments help to classify the behaviour of plants. The effects of organic growth-promoters and of micro-elements are studied. The growth of cultures is determined to some extent by their life history ("the physiological state") and also by the history of the water they are living in. Part I concludes with a discussion of the biomass present in the water and of the relationships between plant production and animal communities.

The record of results given in the first part of the book makes it evident that our knowledge of the general, basic conditions of life in the oceans has made considerable progress, but it is also clear that we are only just beginning to be able to assess the productivity of the sea. We know the principal requirements of the plants, the animals, and the bacteria, but there are nevertheless aspects of the matter about which we know little or nothing. The outburst of plankton in early spring, the succession of different species, the predominance of certain organisms in a given water mass, the deep scattering layer, the migration of animals, the variation in time of the population density of a particular species, and the long-term variation of the stock of a particular fish are some of the problems which are closely related to the question of the productivity of the sea, and which still await solution. The complexity of these problems is such that it is only by team work that definite conclusions can be reached. This is one of the reasons why outstanding specialists in a subject should be able to co-operate without regard to nationality. The principle of proportional participation in international work is inapplicable to fundamental research.

Part II deals with the chemistry of sea water, beginning with chlorinity, salinity, specific gravity, osmotic pressure, and conductivity. The major and minor constituents of sea water are then discussed separately; the latter

includes the organic material dissolved in sea water. In most cases the tables quote the latest values, but it is not always stated whether the figures relate to coastal or oceanic waters. Because most of the micro-elements are more highly concentrated in organisms than in the water itself, the range of concentration may be great and depends on the history of the water mass and the biomass living in it. Copper, arsenic, and iron, for example, are dealt with in detail, but the concentrations given for some of the other elements do not seem to represent the average for the ocean.

The carbon-dioxide system, in which BUCH's new tables are given, is excellently described. Finally, the gases are dealt with and their rates of interchange with the atmosphere are discussed.

In the last chapter, written in collaboration with F. A. J. ARMSTRONG, the technique is described of the analysis of phosphorus compounds, nitrogen compounds, and silica, which makes the book very useful in the laboratory.

HARVEY's new book, dedicated "to all those creatures who live in the sea" not only furnishes the biologist with essential information on the chemical factors controlling life in the ocean, but also describes for the chemical oceanographer the principal biological facts which govern the chemistry and distribution of the micro-elements in the ocean. It is concisely written — the first page seems to me to be a masterpiece — and well printed. It constitutes — as did its forerunners — the latest and most comprehensive collection of facts relating to the fertility of the oceans that exists at present.

F. F. K.

P. Groen. "On the behaviour of gravity waves in a turbulent medium, with application to the decay and apparent period increase of swell." Kon. Nederlands Met. Inst., Med. en Verhand., **63,** pp. 1–23. 's-Gravenhage, 1954.

Water waves invade a region of turbulent water motion, and the problem is to find the decay in wave amplitude resulting from the interaction of the waves and the "external" turbulence. The details of the processes involved are not yet understood and the author is therefore obliged to introduce many assumptions with incomplete justification. Assume, first, that the incident waves consist of a single regular progressive wave-train, and instead of considering its decay in space as it penetrates into the zone of turbulence, consider the simpler problem of a uniform progressive wave-train suddenly superposed on a horizontally homogeneous field of turbulence and decaying in time. Write the velocity at any point as the velocity in the regular wave-train (obtained from the theory of infinitesimal waves), plus a turbulent difference-velocity which includes the "external" turbulence and the interaction of the latter with the wave. (The interaction is assumed to have no velocity component parallel to the wave crests.) The equations for the mean wave motion then contain "REYNOLDS stresses" expressing the action of the difference-velocity on the wave motion. The decay of wave energy can be expressed in terms of two integrals involving the REYNOLDS stresses

(which are unknown and because of interaction bear no simple relation to the external turbulence). One integral is a surface integral which is rejected on physical grounds. (The reviewer finds the breakdown of the mathematical argument at this point disturbing.) The other integral is a volume integral; to estimate this it is assumed that the REYNOLDS stresses can be expressed approximately in terms of the external turbulent velocity and of a "mixing length", and an eddy viscosity is thus obtained. It is now assumed that the mixing length is proportional to the wave-length L and that the equilibrium theory of turbulence is applicable (i. e., that the process of decay is locally isotropic), whence it is deduced that the eddy viscosity varies as $L^{4/3}$. The eddy viscosity at depth z is then written in the form $L^{4/3}\varphi(2\pi z/L)$ where the function φ is assumed to decrease monotonically from the surface downwards. If an exponential form is chosen for φ, it is possible to estimate the time rate of decay. So far the calculations apply to the spatially homogeneous model. A space rate of decay is obtained if the time rate is formally divided by the group velocity appropriate to the wave period. This gives the decay of a single wave-train and is now assumed to hold for each component of the spectrum independently, i. e., interaction between different frequencies is neglected. The change with time of the wave energy and of the significant period can then be calculated and is consistent with known observations. There is a note on eddy diffusion.

The reviewer hopes that this work will be continued until the assumptions are reduced to a more reasonable number.

F. Ursell.

M. Rodewald. "Normalwerte und Abweichungen der Meerestemperatur bei den nordatlantischen Wetterschiffen". Deutsche Hydrogr. Zeitschr., **5**, 2/3, S. 131–140, 17 Abb. Hamburg, 1952.

M. Rodewald. "Die Abweichungen der Oberflächentemperatur des Ozeans bei den nordatlatischen Wetterschiffen 1951–1953". Deutsche Hydrogr. Zeitschr., **6**, 4/5/6, S. 170–185, 13 Abb. Hamburg, 1953.

From a number of already published atlases of temperature means the author first deduces monthly values of the temperature of the surface water at the Weather Ship Stations in the North Atlantic. These are then used as standards against which are compared the means for the separate months during the period November 1950—December 1953, computed from the observations of surface temperature carried out every 3 hours on board the Weather Ships. The anomalies are studied from the point of view of the increase in temperature which is known to have occurred over large parts of the ocean. The thermal anomaly, averaged over all ten North Atlantic Weather Stations for the years 1951–1953, is found to be +0·6°C. The anomaly varies with season, attaining its main maximum in winter and a secondary maximum in summer.

The temperature of the surface water and the temperature of the air over the sea vary in nearly the same way, but the variations in water temperature appear to occur after those in the air.

The air flowing over the oceanic region under consideration comes mainly

from the east coast of North America, and accordingly when the anomalies of air temperature there are compared with those of sea temperature at the Weather Stations, a certain agreement in the variations of the two sets of anomalies appears.

Comparison of the anomalies of water temperature at the Weather Ship Stations with those of air temperature on the west coast of Europe does not yield evidence of any close connexion; the correlation, if any, seems to be negative. On the other hand, it is found that for each of the three years in question the yearly anomaly of surface temperature for the ocean as a whole is about the same as the yearly anomaly of air temperature for the east coast of North America and the west coast of Europe together.

A series of examples shows the manner in which changes in the atmospheric circulation produce changes in the anomalies of water temperature at the various Weather Stations.

J. S.

U. Stefánsson. "Temperature variations in the north Icelandic coastal area". Rit Fiskideildar, **2,** 2, pp. 1–27, 17 figs. Reykjavik, 1954.

The author deals with the sea surface temperature data for the north of Iceland published by the Danish Meteorological Institute in the Nautical-Meteorological Annual, and a series of surface temperature observations begun in 1874 at Grimsey, a small island situated about 23 miles off the north coast of Iceland.

The first set of data is used for the computation of the normal horizontal temperature distribution along the north coast for the period 1901–1930, and also for the computation of 10-year running means for the period 1896–1939. Only the data for the 3 summer months were considered adequate for treatment, however.

These investigations gain much in significance by the inclusion of the Grimsey observations, which were made daily as a rule. Excellent graphs illustrate the variation of the annual mean temperature at this locality, which is shown by 30-year running means, and the variation of the monthly, seasonal, and annual mean temperatures as shown by 10-year running means.

The 10-year means for all months show a decline until shortly before the beginning of this century. During the following years there was no very conspicuous trend, but shortly before the 'twenties a very marked rise took place in all months, but particularly in May, June, and July. The temperature increases from 1911/20 to 1931/40 ranged from 0·87°C. in October to 2·87° in June. After the mid-'thirties the temperatures again decreased, especially in summer and spring, and to a less pronounced extent in autumn and winter.

Possible causes of the temperature fluctuations, such as changes in atmospheric circulation, in local winds and ocean currents, and in the extent of arctic ice, are discussed and illustrated by several graphs and charts. Since the sea surface temperature is influenced by many factors, the problem of what causes the changes is a very complex one; however, it seems that the relatively large temperature rise observed at Grimsey in

spring and summer can be attributed mainly to the combined effects of changes in atmospheric circulation and extent of arctic ice.

The paper is of interest not only in connexion with the hydrography of Iceland, but also in relation to the whole question of temperature variation in the northern seas.

H. Th.

J. C. Freeman, Jr. "Wind mixing currents". Journ. Mar. Res., **13,** 2, pp. 157–165, 4 figs. New Haven, Conn., 1954.

The currents discussed by the author belong to the category of pressure gradient currents, if by pressure gradient current we designate a current, or current component, that is determined mainly by the slopes of the isobaric surfaces at the various depths, in such a way that the Coriolis forces accompanying the current are mainly balanced by the horizontal pressure gradients in the water.

In the case of the particular type of current called "wind mixing currents" by the author, the slopes of the isobaric surfaces are caused by differences of wind mixing in a two-layer ocean. Let us suppose, firstly, that the upper mixed layer is of uniform thickness and density throughout the sea area considered and that below the thermocline the surfaces of equal density are horizontal and coincide with the isobaric surfaces. Suppose, then, that a strong wind, associated with vigorous mixing across the thermocline persists in one section of the sea area, while a weaker wind, which causes little or no mixing, occurs elsewhere. Under the strong wind the upper mixed layer becomes deeper, its density increases (because of mixing with colder water) and, consequently, the subsurface isobaric surfaces within the mixed layer are raised. In the transition area between the area of strong mixing and the area of weak mixing, the isobaric surfaces within the mixed layer therefore become sloping, which gives rise to pressure gradient currents.

For the case of geostrophic balance, the author gives equations which express the current velocities in terms of the horizontal density gradient involved and the depth of the layer considered.

From observations made at the Atlantic Ocean Weather Stations "C" and "D" he derives a transport due to the "wind mixing current" of 0·4 ft^2./sec., which is from 10 to 20% of the net transport directly due to the wind stress occurring during the 10-day period considered (Sept./Oct. 1949).

P. Groen.

Wolfgang Krauss. "Zum System der Meeresströmungen in den höheren Breiten". Deutsche Hydrogr. Zeitschr., **8,** 3, S. 102–11, 4 Abb. Hamburg, 1955.

In recent years MUNK has attempted to explain the oceanic circulation on the global scale entirely on the basis of the wind's stress. According to his theory, the circulation in subpolar latitudes assumes the form of a cyclonic "gyre". Qualitatively, this agrees quite well with the actual circulation in the Norwegian Sea, for instance. In the opinion of KRAUSS, however, there is evidence that factors other than wind stress determine the circulation

in these latitudes. The wind field in the higher latitudes of the North Atlantic is such that it seems doubtful whether the currents can be caused by the wind stress. Firstly, the author argues, the winds are so variable that it is unlikely that they could give rise to a relatively steady current system. Secondly, in many cases the average winds oppose the direction of the currents (this, however, is not in itself incompatible with MUNK's theory).

The author's main hypothesis is that so variable a wind field can result only in large-scale turbulence, not in a semi-permanent current; and that the origin of the existing current system in high latitudes must be sought in the solenoidal field off the coasts, which is produced by the supply of fresh water from land. The existence of such a field is well known, and the author has computed, with considerable mathematical skill, the salinity field resulting from a line-source of fresh water along a coast. This mathematical derivation adds, however, nothing to the argument. The velocities which can be computed from the salinity field, be it observed or calculated, are about 10 cm./sec. at the surface near the coast, and much less the deeper down in the water or the further from the coast we go. (The velocities given in Figure 4 of the paper are too high; the correct values will appear in No. 6, 1955, of D.H.Z.) In the author's opinion, such coastal currents constitute the primary current system in relatively high latitudes, and currents such as "Atlantic" or "Polar" currents are secondary phenomena dependent on the former. To the reviewer, it seems strange that the relatively weak coastal current over the shallow shelf should govern the course and extent of the Atlantic current in the Norwegian Sea, for instance, with velocities probably of about half a knot at the surface and exceeding 10 cm./sec. at several hundred metres depth.

However, the present paper is intended only as a preliminary sketch of the author's ideas. He promises us a comprehensive account of his theory, which will be published in the "Meteor" Reports; in this he will presumably present stronger arguments for his hypothesis.

O. H. S.

C. C. Davis. "The Marine and Fresh-Water Plankton". 562 pp., 681 figs. Michigan State University Press, Chicago, 1955.

A book on plankton is long overdue, especially in the United States where library facilities at many colleges and marine stations are limited. As the author remarks in his preface, "The literature on the plankton is both voluminous and scattered". He adds "To the modern plankton student ..., the major reasons for a taxonomic study of the plankton, except in areas previously unexplored or inadequately explored, would be to obtain a better and more precise basis for ecological studies". DAVIS's book, intended as a text-book for university students, is an attempt to provide the background for ecological studies and the means for identifying planktonic organisms according to genera.

The questions at once arise as to whether it is possible within so short a volume (279 pages of text plus 186 pages of drawings) to present even a brief outline of all the material that must be considered and whether any one person alone can undertake the task. The present reviewer, for example, is

not sufficiently familiar with developments in limnology to make any critical appraisal of the portion of the book concerned with freshwater environments. Comments are therefore omitted for these sections other than to note that few of the many recent papers from Central Europe, Great Britain, and the Scandinavian countries, or even from the United States and Canada, appear to have been consulted.

With the rapid strides in the marine sciences since the end of World War II, the portion of the book concerned with the oceans and the organisms dwelling there appears outmoded on publication. Several shorter, more up-to-date books[1]) antedate this one by only a few months. Yet they contain information that would have been of inestimable value in bringing certain topics up-to-date through 1954.

It appears unfortunate that HARVEY's two earlier books (1928, 1945) were not available to the author as they, together with the many significant references cited in their bibliographies, would have clarified points that seem confused in the first part of the book. Thus, "the temperature of the ocean water varies with latitude and with depth" (p. 22), but no mention is made of the important seasonal temperature changes. The development of an annual thermocline has not been considered at all, because "the open ocean is sufficiently vast that there seldom develops a thermal stratification as occurs in freshwater lakes ... nor is there a spring or fall overturn" (p. 23). While the term "open ocean" as used here may apply to offshore waters deeper than 200 metres (judging from Figure 8), a thermocline does develop in waters of the open ocean as well as in shallower boreal and arctic seas.

In disregarding the importance of the thermocline in the plankton economy of the sea, the author has failed to appreciate how the nutrient salts are restocked in the surface layers over the continental shelf. Thus, he states "Freshwater drainage from the land, carrying nutrients with it, pours into the neritic province [i. e., the continental shelf]. In addition, in the neritic province, plant nutrients are not so readily lost by sinking deeper than the zone in which plant life can exist. Thus production in general, and plankton production in particular, is much higher near shore than in the oceanic pelagic region" (p. 24), an idea repeated on page 63. "On the other hand, it has been shown that the surface waters in temperate regions have sufficient nutrient salts at all times of year for adequate phytoplankton growth" (p. 71).

These misconceptions imply that the author is not aware of the great mass of oceanographic information obtained over the last 50 years or more in the boreal waters of the continental shelf on both sides of the Atlantic. This impression is strengthened by comments about the lack of information in "high latitudes". Thus, "a more thorough study of production is needed in Arctic and Antarctic seas" (p. 59), "Of course, most plankton investigations of waters in high latitudes have been made during the summer months

[1]) H. W. HARVEY's "The Chemistry and Fertility of Sea Waters", Cambridge University Press (1955), 224 pp., and S. M. MARSHALL and A. P. ORR's "Biology of a Marine Copepod", Oliver and Boyd, Edinburgh (1955), 188 pp.

and it is probable that the total production for the period of a whole year would average not as high as the apparent productivity indicated by summer analyses alone" (p. 60), "Of course, in plankton observations — especially the hit-and-run observations heretofore usual for high latitudes — it is the standing crop that is measured" (p. 61) and "practically no year-round studies have been made at high or low latitudes" (p. 69). The readers of the *Journal du Conseil* will not need to be reminded of the vast amount of work in north European waters or of the "Discovery" surveys carried out in every sector of the Antarctic in each month of the year.

Perhaps it was due to the lack of access to the literature (suggested on page 58) that the section on the history of plankton studies is hardly adequate. The history of the International Council for the Exploration of the Sea (cf., BUCH, 1952; THOMSEN, 1952; WIMPENNY, 1952) during the last 50 years is in itself the history of the development of modern attitudes in marine plankton ecology and a summary of this would have been an excellent introduction for the beginner.

The omission of descriptions of laboratory and field plankton methods (and their limitations) is a definite handicap for a student just embarking on the study of plankton ecology. In STEUER's *Planktonkunde* (1910), the only book at all comparable, nearly one-tenth the volume was devoted to description of methods and apparatus. With developments of the last 45 years, these sections are badly in need of modernization.

The readily accessible keys, in DAVIS's book, to the genera of all planktonic groups constitute a real advance. Unfortunately, these are presented without reasons for the selection of some genera and not others of equal prominence, without indications of how reliable or up-to-date the keys may be, and without discussions of taxonomic rules and procedures. The key to the Radiolaria (based chiefly on HAECKEL's (1887) "Challenger" monograph) occupies $6\frac{1}{2}$ pages and there are roughly 100 species figured (or 15% of the total). This seems disproportionate for a group encountered rather infrequently in plankton samples. In contrast, little space is given to ecologically important groups, such as diatoms, dinoflagellates, copepods, etc. The need for a taxonomic revision of the coccolithophorids resulting from electron microscope studies has been overlooked.

Trial runs on several keys indicate that some are misleading and at least one is truly unworkable. For example, a number of the copepod genera listed as freshwater inhabitants also have marine or at least brackish-water representatives. The key to the medusae (based almost entirely on MAYER's (1910) three-volume monograph) works fairly well for the genera selected, provided others be excluded from the collection and provided one knows the terms, which are not always included in the text or in the glossary. However, without considerable familiarity with the synonomies[1]) in this group, it would be difficult to determine the names generally accepted today, for the species illustrated. A number would be found in the synonomy of other species. Many are not referred to the correct authors. (Not included in the key, but mentioned in the text as "rare" is the freshwater genus

[1]) Lists of synonyms. Ed.

Craspedacusta, which RUSSELL (1953, p. 411) states "can no longer be called rare".) The key to the siphonophores, intended for an "entire or reconstructed colony" (p. 208), is unworkable. Firstly, it would be difficult for the beginner to "reconstruct" the colony preparatory to its identification! Secondly, there are few definitions of terms, especially those for bilaterally symmetrical animals when applied to siphonophores. A diagram to indicate how these terms are used is almost a necessity because specialists in the group are not in agreement on terminology. The wording of the key is ambiguous and may lead to a particular genus, but there are several other genera which have not been excluded along the way. The genus selected is no more abundant than the others, and this again raises the question as to how genera were selected. The key to the Foraminifera is open to these same criticisms, perhaps because CUSHMAN's 1948 volume was unavailable.

In approaching the identification of planktonic organisms, the student must use entirely new techniques. He will need to consult original papers and monographs written by specialists and to have some knowledge of taxonomic practises and terminologies. These procedures are not described in the usual elementary text-books nor in DAVIS's book.

Keys are, at best, only a guide, and are limited in their use. They should be amplified (1) by the inclusion of well labelled diagrams and (2) by adequate descriptions to verify the identifications made by the keys alone or by references to such descriptions. The value of diagrams is well recognized by many specialists today (cf., *Das Tierreich*, *Faune de France*, RUSSELL's *Medusae of the British Isles* (1953), *The Euphausiacea* (*Crustacea*) *of the North Pacific* (1955) by BODEN, JOHNSON, and BRINTON, etc.). A few well drawn and well labelled diagrams might with advantage have replaced pages of the indifferently reproduced figures in DAVIS's book[1]). Without the inclusion of descriptions of the genera — hardly to be expected in a volume of limited size — the keys lead to an impasse, because the references provided at the end of each key are not always the most helpful or the most up-to-date. The keys in DAVIS's book will therefore not prove to be especially useful in identification even as regards genera.

In the bibliography, the 300-odd references include very few published after 1946. If space is limited, it would seem preferable to include (1) books and review papers which provide summaries and citations of background information and (2) the most recent and most helpful monographs for the taxonomy of planktonic organisms. The selection seems to have been quite unsystematic. Many important references are omitted, some cited in the text do not appear in the bibliography, and some that are included are not particularly pertinent.

The second half of the book is not conveniently arranged. The keys and text are separated from the figures by the glossary (of fewer than 200 terms)[2]), the bibliography, and the legends for the figures so that the reader has to

[1]) Two labelled diagrams were included but they were not labelled to conform with the text, key, or glossary.

[2]) The glossary is prefaced by the suggestion that omissions be sought in the index so that they may be located in the text. In many instances the terms do not appear in the index.

turn pages repeatedly. In desperation a beginner may flip through pages of figures with the hopes of recognizing a "creature" he cannot otherwise identify. Even this presents a problem, chiefly because the identifying characteristics have become obscured through poor reproduction, as in the Foraminifera, or because the relative sizes of the organisms are not always shown. For example, on pages 536–537, it would appear that *Oikopleura* and *Fritillaria* are perhaps as large as the salp and doliolid on the opposite page and that *Pyrosoma* is rather smaller. Actually, the first two are magnified perhaps ten times, the salp is close to natural size, but *Pyrosoma* "may attain an enormous size (several yards long)" (MURRAY and HJORT, 1912, p. 559). The legends do not clarify this particular point and they are also inadequate in other respects. Thus, the legends to Figures 419, 420, 424, and 425 merely give the siphonophore species, without signifying which fragments are illustrated.

This notice cannot be concluded without mention of the unusual number of errors, particularly in the legends. The legends to Figures 426 and 427 have been interchanged. Figure 423 is not *Bassia*, but presumably *Chelophyes appendiculata*, although the characteristic shape and features have been lost on redrawing. Species are frequently incorrectly assigned to authors. *Abyla leuckartii* (now referred to *Ceratocymba*) was first described by HUXLEY, not QUOY and GAIMARD; *Solmaris octona* by KEFERSTEIN and EHLERS, not HAECKEL; *Dipurena strangulata* by MCCRADY, not HAECKEL; *Linuche unguiculata* by SCHWARTZ, not ESCHSCHOLTZ; and *Aglantha digitale* by MÜLLER, not HAECKEL. In some cases, L. and A. AGASSIZ have been confused; GEGENBAUR's and STEEMANN NIELSEN's names are consistently misspelt. *Geryonia* (spelt *Sergonia*) was more puzzling until it became apparent that a handwritten *G* had been confused with an *S* and a *y* with a *g*! Other examples might be cited.

The reviewer has gone into some detail to caution the prospective reader that DAVIS's rather expensive book is not the panacea the author had hoped. We trust this will not deter the author from trying to achieve his purpose, but rather encourage him to revise it, so that one day we may have the much needed volume or volumes. He has indeed assigned himself a most difficult task and perhaps even a discouraging one, but it is one that should be done before long.

M. S.

D. J. Crisp and **P. A. Davies.** "Observations *in vivo* on the breeding of *Elminius modestus* grown on glass slides". Journ. Mar. Biol. Assoc. U.K., **34**, 2, pp. 357–380, 7 figs. Cambridge, 1955.

This shows us how to analyse the breeding activity of an animal from warmer latitudes (e. g., Australia) which lacks the seasonal breeding cycle found as a rule in less equable climates, but merely shows variations in breeding activity, according to whether conditions are favourable or not. We are introduced to the concepts of a fertilization constant (the proportion fertilizing or spawning in a given time of that fraction of the population which is not already incubating embryos) and a liberation constant (the

rate of liberation of larvae by gravid individuals). The data were obtained by allowing populations of this immigrant barnacle to settle on clear-glass plates, which were then suspended in the sea from a raft. The condition of the ovaries and the state of development of embryos could be examined periodically, through the glass and through the transparent bases of the barnacles, with the minimum of disturbance, individuals being identified photographically.

A few *Elminius*, which had settled in June, were mature less than 8 weeks later, having reached basal diameters of 4–6 mm. Within 10 weeks of setting, half the population was mature. Each mature individual embarked upon a succession of cycles, each cycle involving copulation, oviposition, fertilization, incubation and liberation of a brood. By September the population had reached a breeding state indistinguishable from that found in populations of older individuals.

After oviposition, the embryos were retained in the mantle cavity for about 10 days in summer, at 18°C., and 60 or more days in winter, at 5–10°. Meanwhile the ovaries gradually recovered. In summer they were generally ripe again by the time liberation occurred and in most individuals a fresh cycle followed with little delay. Only 10–20% of individuals showed longer delay between cycles, the ovaries having probably failed to reach maturity. In autumn and winter, however, ovarian regeneration was much slower, not only absolutely, but also relatively to the rate of embryonic development. Periods without embryos therefore intervened between successive cycles, in spite of the great increase in the time of incubation. Ovarian regeneration was probably limited by food and temperature, development of embryos by temperature alone.

Further analysis of the relations between reproduction, temperature, and the seasons showed that fertilization occurred more readily in the spring than at the same temperature in the autumn, probably because food was more abundant in the spring. Liberation also occurred more readily in the spring, a surprising fact which seems explicable only in the light of the evidence, since made known by Dr. Crisp at a recent meeting of the Challenger Society, that an egg-hatching substance is produced by gravid barnacles in response to the presence of food in the water. This seems to be the first record of the young of incubating marine animals tending to be retained as embryos until food is available for their independent life.

Barnacles kept without food soon ceased oviposition altogether. Others, with better access to food than their neighbours, not only grew faster than the latter, but were more prolific breeders at a given size. Larger barnacles were more prolific than smaller ones in the same environment. Individuals observed for three years showed no senescent falling-off in breeding activity. There was no trace of tidal periodicity in breeding.

Assuming a span of life of 3 breeding seasons, and averages of 500 eggs per brood and 12 broods per season, the total output of young approaches 20,000 per individual. The generation time during the summer is only about 14 weeks. Evidently the future status of *Elminius* as a fouling organism is well assured.

E. W. Knight-Jones.

A. L. Tester. "Estimation of recruitment and natural mortality rate from age-composition and catch data in British Columbia herring populations". Journ. Fish. Res. Board Canada, **12,** 5, pp. 649–681, 8 figs. Ottawa, 1955.

The detailed study of the behaviour of fish populations under exploitation involves the estimation of certain characteristics of the population, notably the growth and mortalities. Of these the natural mortality is generally the most difficult to estimate, and most methods of doing so involve some knowledge of the fishing intensity applied over a period of years. However, there are many fisheries for which, either through lack of adequate statistics, or because of the variable behaviour of the fish, a good index of the true overall fishing intensity is not available. An example of the latter is the British Columbia herring fishery, and in the paper under review a method is developed whereby the natural mortality (and hence also recruitment) may be estimated from the catch statistics and total mortality only.

If the fishery is in a steady state, then the proportion of a year-class caught during its whole life-span is equal to the ratio of the fishing to the total mortality rate; i. e., the number caught out of R recruits is given by

$$C = \frac{F}{F+M} R \text{ (with the notation that is more familiar to European workers)}$$

$$\text{or, rewritten, } (F+M)\, C \frac{1}{R} = F = (F+M) - M$$

$$\text{or } F + M = M + \frac{1}{R}(F+M)\, C$$

or in the notation of the paper

$$i = q + \frac{1}{R} i\, C \ldots\ldots\ldots (1)$$

If recruitment and natural mortality are presumed to be constant during two or more periods of equilibrium, with different values of total mortality and catch, then q (natural mortality) and R may be estimated either from the simultaneous equations

$$i_1 = q + \frac{1}{R}\, i_1 C_1$$

$$i_2 = q + \frac{1}{R}\, i_2 C_2$$

if there are only two periods, or by a regression of i on $i\,C$ for several periods.

This method has been applied to various sets of data for the British Columbia fisheries, with the regression of i on $i\,C$ for data of 20 years or more. The plots gave some correlations that look very good (e. g., Fig. 7), and resulted in estimates of natural mortality from 0·4 to 1·2, generally increasing with age. The corresponding estimates for stock size agreed well with independent estimates from spawning surveys. While this agreement is very satisfactory, there is a possibility that it is to some extent fortuitous, and that the good observed regression of i on $i\,C$ obtained from equation (1)

is due to causes other than those given in the paper. The possible factors whereby an observed pair of values of i and $i\,C$ can depart from the average include (a) variations in fishing, (b) changes in natural mortality, (c) changes in recruitment, (d) sampling and other variations in estimating the total mortality, i. Of these (b) and (c) will give simple random scatter, and (a) of course gives the predicted regression line, but (d) will make high (or low) values of i and $i\,q$ occur together and hence tend to generate a false regression line passing through the origin. This can be avoided by rewriting equation (1) in the form

$$R = qR\,I/i + C \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

and plotting a regression of I/i against C, which should give a slope equal to $-qR$ and an intercept of R. Applying this method for areas 23–24 of the British Columbia herring fisheries gave no very clear regression line, which suggests that the observed regression from equation (1) is in large part due to variations in the estimate of total mortality.

However, in the modified form the method does provide a means of estimating natural mortality when there is no adequate measure of fishing effort; that is, when most of the standard methods cannot be applied.

A minor criticism of the paper is the presentation of data in the form of "catch curves", i. e., the logarithms of numbers at each age. Though this is a most useful form for a single sample of age composition, it is less efficient when samples are taken regularly each year. Then it is surely possible to estimate total mortality for each year-class for any pair of successive years, which will be independent of recruitment variations, and which can be shown directly. In the present paper the increase in total mortality with age is important, but is only shown as a convexity in the catch curves (Figures 3 and 6), and is not easily appreciated. *J. A. G.*

T. M. Widrig. "Method of estimating fish populations, with application to Pacific sardine". U.S. Fish & Wildl. Serv., Fish. Bull., **55**, 94, pp. 141–166, 5 figs. Washington, 1954.

The fishery for the pacific pilchard or sardine has, particularly in recent years, undergone violent fluctuations. The causes of these fluctuations are not definitely understood, but two important factors are likely to be changes in the natural mortality and the availability, i.e., the fraction of the population which lies within the range of the fishery. In the present paper, methods are developed by which, if certain assumptions about one of these factors are made, changes in the other can be measured. The author first develops the regression formula for total mortality on fishing effort, including the expression giving the effective overall effort in terms of effort and catch in sub-areas of the whole fishery. So long as the whole population is available to the fishery this regression is a straight line. Widrig then considers the case when only part of the population is available during the fishing season, assuming that the pattern of fish movement is such that there is complete mixing between fished and unfished sections during the period between fishing seasons, and that during the next season a random section of this

mixed population becomes accessible to the fishery. Under these conditions the regression line becomes a curve, concave downwards. However, at moderate effort the departure from linearity is small, and a correction term is given for exact work. The intercept of the regression line on the axis gives the value of total mortality with zero fishing, i. e., the natural mortality. When this is known, the population size can be estimated directly from the catch and the fishing mortality (i. e., total mortality less natural mortality).

So long as the availability is constant, the mortality observed in the fished section of the population from one season to the next will be the same as the true mortality of the whole population. However, if the availability increases, say, in one season, then the apparent survival will be greater than the true survival. Thus departures, other than pure sampling errors, from the regression of total observed mortality on effort, may be interpreted as being changes in availability, alternative explanations being changes in natural mortality, or possibly incorrect measurement of real fishing effort. By ignoring the last, and assuming one of the former quantities is constant, a series of changes in the other can be determined. This method has been applied to the data of the Pacific sardine, and if availability is assumed to be constant, minimum values of natural mortality (on the assumption that the lowest mortality, in 1935–6, was zero natural mortality) ranged up to 1·88 (in 1945–6), with an average of about 0·6. The corresponding minimum estimates of the population size for each year varied between 3 and 40 billion fish. If it is assumed that natural mortality was constant, and the availability in 1936–7 and 1949–50 (the year of highest availability) was 100%, the estimated availability in the other years ranged from 15+ to 90%, the minimum estimates of population size being 6 to 17 billion fish. The range in natural mortality is unreasonable, and it is concluded that some at least of the variation must be due to changes in availability.

It is perhaps unfortunate that no attempt is made to deal with what some authors have also termed availability, but may be better termed vulnerability; i. e., changes in the catch by the same apparent effort due to changes in behaviour of the fish (e. g., shoaling) even when the fish remain within the geographical range of the fishing fleet. However, the paper represents an important step in the post-recruitment population dynamics of the Pacific sardine, and develops methods which are likely to be of importance in any fishery which may be exploiting only part of the range of a migratory fish stock.

J. A. G.

T. Yoshihara. "On the distribution of catches by tuna long-line". Journ. Tokyo Univ. Fish., **41,** 1, pp. 1–26, 11 figs. Tokyo, 1954.

The Japanese fishery for tuna is one of the most important in the world, accounting in 1953 for some 46% of the total world production of tuna and tuna-like fish. Lining is the principal method of capture employed, most of the lines being of the surface-fishing type, although a substantial quantity is taken by subsurface long-line gear.

The latter type of gear consists of a main line from which are hung branch

lines, or snoods, carrying hooks at a depth of 30 to 200 m. The depth to which the hooks are lowered is decided mainly by the species of fish it is desired to catch, albacore being found mainly at a depth of 30 to 100 m., black, big-eyed, and yellowfin tuna being taken mainly at deeper levels. The main line is suspended by lines from floats (float lines) which may be set at intervals of anything from 200 to 300 m. along the main line. The line between two floats is usually termed a basket. The depth at which hooks fish is determined by the number and spacing of the float lines and the spacing and length of the branch lines, and several variations in construction are employed. Each line may consist of 300 to 400 baskets.

For a number of years Japanese scientists have explored fishing grounds with a view to helping to promote an active and productive offshore fishery for tuna. In particular, they have paid attention to the depths of the swimming layers of different species and also to the correlation of catches at different depths with hydrographic data.

The paper under review presents some of the data collected in the course of these extensive investigations and studies in some detail the horizontal and vertical distributions of three sets of catches by vessels working in the Pacific Ocean during 1949, 1950, and 1952.

The first part of the paper deals with a method of determining the depth of fishing of each hook from the known dimensions of the length of a basket and the length of the float and branch lines. On the assumption that the form of the main line between two float lines, one at the beginning and the other at the end of a basket, is a catenary, the co-ordinates (and hence the depth) of any point on the line may be easily written down. Unfortunately these co-ordinates depend on a quantity not readily determined in practice. The author, however, goes on to show that the required co-ordinates may be obtained indirectly from the ratio of the distance apart at which the float lines are set to the known length of the main line.

A table and a graph have been prepared to facilitate the conversion of this ratio into the required co-ordinates and the actual depths of the hooks in baskets of five and six hooks, for unit length of main line, are presented. It is pointed out, however, that the main line may not have the form of a catenary, in which case the depths given by this method are, of course, not accurate.

The rest of the paper deals with the spatial distribution of the different species based on actual catch data. For one particular set it was possible to determine the absolute depths of the hooks by means of the method developed in the first part of the paper, and the observed distribution of species with depth is obtained for this set. For the other data the spatial distribution is obtained in general terms by noting the distribution of the species between hooks within baskets. The observed distributions show very interesting features. It appears, for example, that sharks were most abundant at the intermediate depths (around 140 m.) while the abundance of big-eyed tuna increased steadily with depth.

The paper concludes with some comments on the relationship between catch and water temperature. Here the author has not a great deal to

contribute. Very few temperature data appear to be available and what data exist seem to suggest that, for big-eyed tuna at any rate, swimming level is not influenced to any appreciable extent by water temperature. The normal distribution is suddenly introduced as an assumed form for the vertical distribution of tuna, but as this assumption is not utilized its introduction seems out of place. The author intends to consider the influence of water temperature in more detail in a future publication. *J. P.*

F. W. F. Morawa. "Wachstum, Wachstumsbedingungen und Aufwuchsplätze des Sprottes (*Clupea sprattus* L.) in der Ostsee". Zeitschr. Fisch. u. d. Hilfswiss., **4**, N.F., 1/2, S. 101–136. Radebeul & Berlin, 1955.

The present paper on the growth-rate and growth-rate features of the sprat in the Baltic, with special reference to the sprat in Kiel Bay, describes the results of very important investigations, which contribute greatly to our knowledge of the biology of the sprat. Before dealing with his own investigations, however, the author surveys the different, sometimes contradictory, methods used earlier for determining the age of the sprat, especially in the Baltic. The conclusions at which the author arrives are no doubt well founded.

For comparison and control, supplementary samples from the North Sea, Kattegat, the southern Baltic, and Danzig Bay were investigated. Regarding growth-rate the author finds that the modal length of larvae and post-larvae increases from 5 mm. in May to 51 mm. at the beginning of September. This is in good agreement with observations made off the west coast of Sweden. He finds, further, that the average lengths of the 0-, I-, II-, and III-groups, at the end of the growth period, are 9, 12·5, 14, and 15 cm. respectively. These also agree well with comparable figures found for the sprat of the same age in the southern Baltic and, indeed, for the whole region from the Skagerak through the Kattegat to the neighbourhood of Bornholm. On the other hand, the length increment of Danzig Bay fish is somewhat less. The general rule that female fish grow faster than male is also seen to hold for sprat, but the difference does not become evident until the beginning of the second year.

In Kiel Bay the majority of the sprats spawn at one year old. The investigations showed that in April–May females of 9·5 cm. length and males of 9 cm. had for the main part reached maturity. This observation is of considerable interest, especially when comparison is made with the age at maturity in other regions; for instance, the sprats off the west coast of Sweden normally spawn for the first time when two years old, and one-year-old spawners are only met with in restricted localities in the skerries. The question remains, What are the special conditions within the localities in question which determine the rate of development of the sprat up to sexual maturity? In connexion with the spawning biology, the difference in fat content of mature and immature individuals is pointed out. It is of interest to note, however, that relatively small quantities of fat were found in four-year-old sprats, a fact which is regarded by the author as a sign of commencing

senility. The consequence of this should be that fish of this age die after spawning. Whether this is a local phenomenon or a feature of more general prevalence, is a question which has yet to be solved.

As regards the annual growth of the sprat in the region studied, the author shows that there is no growth during the winter months proper. In the case of young fish the annual increment takes place during the period April–December, whereas in adult fish growth is limited to July–December, as it does not commence until spawning has been completed.

The food of the sprat consists mainly of Entomostraca, but eggs and larvae of fish and larvae of Malacostraca make up part of the food. The intensity of food consumption depends on water temperature and is minimal during spawning. When the gonads have developed to their full size, they occupy the whole body cavity and cause a pressure on the stomach which prevents it from being filled to the same extent as at other times. As to weight, it was found that the sprat weighs least in February and most in September, in good agreement with earlier observations. In this respect there appears to be no difference between the sexes.

The author mentions that the largest sprat from the Kattegat he has seen was 18·2 cm. long; it may be noted, however, that in Swedish landings from the Skagerak and Kattegat sprats up to 19·5 cm. have been observed.

Arvid R. Molander.

D. R. Swift. "Seasonal variations in the growth rate, thyroid gland activity and food reserves of brown trout (*Salmo trutta* LINN.)". Journ. Exper. Biol., **32,** 4, pp. 751–764, 5 figs. Cambridge, 1955.

This paper reports an experimental investigation of factors which control growth in the brown trout. Difficulties attending such work in the wild and under too restricted laboratory conditions are discussed and there is a detailed section on experimental methods and relevant biochemical techniques.

In 1953, 250 3-year-old hatchery-reared brown trout were kept in two stew-ponds each of 12·5 kilolitres capacity. Random samples of 50 fish were measured each month and returned to the ponds. However, fish used for other aspects of the work were sacrificed at intervals and the steadily diminishing population, and a suspected insufficient feeding level, introduced errors into the growth investigation. These were overcome in 1954 by studying a population of 100 3-year-old fish in one pond and weighing and measuring all the fish separately each month.

This work has established that growth in length shows two peaks, the first towards the end of April (temperature 8–12°C.) and the second in August (temperature 15–16°C.). Growth decreases during the autumn to a low winter level. Growth in weight varies in a similar manner though the peaks occur somewhat earlier. It is suggested that the greater activity of the fish which occurs in June and early July is thyroid-mediated and makes an increased demand on the available food. This is believed to account for the fall in growth-rate which is observed at this time. It is further suggested that the spring increase in growth-rate, which occurs even though the temperature

is still low, is due to the action of pituitary growth hormone. The concomitant importance of increasing day length is mentioned in this context, presumably in reference to the possible effect of daylight on the pituitary gland. The low autumnal growth-rate appears certainly to be due to the demands made by the ripening gonads on available food reserves.

A monthly analysis of liver, gonads, gut, and muscle was also made, in which total water, protein, fat, and glycogen were measured. The tissue analyses show that the composition of muscle and liver is remarkably constant, apart from the liver glycogen of the females, which decreases in autumn. These results contrast with those obtained for herring by previous workers, in which the fat content of muscle and liver vary seasonally. The fat content of the gut wall in the brown trout was found to vary widely throughout the year. A peak value of 23% was obtained in July; this was reduced to 5% by October when the fish were ripe. The gut thus appears to be the main storage organ for fat.

During the period of ripening of the fish, the protein content of the ovary rises to 16% and that of the testis to 10%. The fat content of the ovary rises to 3%. In both gonad and gut the water content varies inversely with fat and protein.

Swift draws attention to the fact that the role of the thyroid gland in teleosts is still largely in doubt and makes an important contribution to our knowledge of thyroid metabolism in the brown trout throughout the year. Existing estimates of thyroid activity are suspect owing to difficulties inherent in the techniques employed, or to the doubtful validity of the criteria used to indicate activity (notably epithelial cell height). The vast majority of teleosts have diffuse thyroid glands which cannot be removed by surgical procedures; consequently other methods of investigation must be used. Previous workers who have measured uptake of radio-active iodine as an index of the metabolic activity of the thyroid gland of fish have done so by wet-ashing the entire lower jaw and measuring its radio-activity. This method is obviously open to criticism and suffers from the major disadvantage that only one measurement of radio-activity can be made on each fish. In the work under review, a more satisfactory technique has been evolved in which the anaesthetized fish are placed over a lead-shielded Geiger-Müller tube at intervals of 6, 24, 48, and 72 hours after injection of ^{131}I at a dose level of 0·1 μc. per g. body weight. A regression coefficient is calculated from the measurements of radio-activity so obtained and used as an index of thyroidal activity. The validity of the method relies on the assumption that the turnover of ^{131}I will be faster when the gland is active. This seems to be a fair assumption and it is probably the most acceptable criterion of thyroid activity, in a physiological sense, in the absence of a method for measuring the level of circulating thyroid hormone. The results obtained are plotted graphically and a curve is drawn through the monthly means of the regression coefficients. This shows a major peak in June and a minor peak in February. The variability between individual fish is large and in some cases mortality appears to have been high, so that the number of values from which the means have been calculated is rather small. However, there seems little doubt that the most rapid turnover of iodine by the

thyroid gland occurs in midsummer, and this is the time at which the fish are most active. It is suggested that this increased activity makes a greater demand on available food stores and accounts for the slow summer growth-rate of brown trout. This is an interesting suggestion, and if corroborated, it would add significantly to the little that is known about thyroid gland function in cold-blooded vertebrates.

J. M. D.

Current Bibliography

Prepared by the Editor with the Assistance of Mr. A. R. MARGETTS

NOTE. The scope of the Bibliography is limited in the main to the area covered by the Council's activities, but there are included papers of general interest relating to other areas in North Temperate and Arctic regions and exeptionally elsewhere. Limnological references are not as a rule given, but papers relating to brackish waters and to salmon and freshwater fish studied by the Council are included.

Subscribers and those on the distribution list will receive regularly upon application to the General Secretary copies of the Bibliography printed on one side of the page only, for use in making up card indices.

The Editor will be glad to be advised of emendations and additions to the Bibliography.

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